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BIOLOGY DATA BOOK

Compiled and Edited by

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FEDERATION OF AMERICAN SOCIETIES FOR EXPERIMENTAL BIOLOGY

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NOTICES

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BIOLOGY DATA BOOK

FOREWORD

The Biology Data Book is the third of the Biological Handbooks to be issued under the general direction of the Committee on Biological Handbooks of the Federation of American Societies for Experimental Biology, Washington, D. C. This volume continues a series of handbooks prepared under the auspices of the National Academy of Sciences-National Research Council, the first of which was published in 1952.

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Dr. J. W. Heim, Technical Director of the Biophysics Laboratory, Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio, was the technical monitor for the Air Force. The Air Force participation in this undertaking is in support of Project No. 7164, "Biomedical Criteria for Aerospace Flight," Task No. 716406, "Systemization of Biological Knowledge."

The Committee on Biological Handbooks acknowledges with thanks the contribution of 470 botanists, zoologists, and basic medical scientists who have contributed so generously with their time and advice. The Committee thanks the National Institutes of Health, the National Science Foundation, and the Aerospace Medical Research Laboratories for the generous support and cooperation that have made possible the production of this book.

This technical report has been reviewed and is approved.

J. W. HEIM, PhD
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ABSTRACT

The Biology Data Book has been compiled to present numerical data of biology and medicine in a convenient and accessible form for reference, and to standardize accepted constants as a basis for correlation, establish common standards for statistical studies, and provide normal values for research. The biology data are organized in the form of tables, diagrams, charts, and graphs, arranged under the following headings: Genetics and Cytology, Reproduction, Development and Growth, Morphology, Nutrition and Digestion, Metabolism, Respiration and Circulation, Blood, Biological Regulators and Toxins, Biophysical and Biochemical Characteristics, Environment and Survival, Parasitism, and Materials and Methods. Seven appendices provide information concerning estimated number of species, taxonomic classification for living plants and animals, geologic distribution, atomic weights, as well as logarithms and antilogarithms. A detailed index completes the book. The contents have been authenticated by 470 authorities in the fields of biology and medicine. The review process of the tables was designed to eliminate, insofar as possible, errors of transcription and material of questionable validity.

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ABBREVIATIONS AND SYMBOLS

Measurements

ht = height
mi = mile
ft = foot
in. = inch
m = meter
km = kilometer
dm = decimeter
cm = centimeter
mm = millimeter
μ = micron
mμ = millimicron
Å = Ångström unit

yr = year
mo = month
wk = week
da = day
hr = hour
min = minute
sec = second

cgs = centimeter-gram-second
rpm = revolutions per minute
ft-c = foot-candle
atm = atmosphere

sq = square
cu = cubic

wt = weight
lb = pound
g = gram
kg = kilogram
mg = milligram
μg = microgram
μμg = micromicrogram
mEq = milliequivalent
gr = grain
M = mole
mM = millimole
μM = micromole

L = liter
ml = milliliter
μl = microliter
I.U. = international unit
ppm = parts per million
vol % = volume percent

°C = degrees centigrade
°F = degrees Fahrenheit
cal = calorie
kcal = kilocalorie
BTU = British thermal unit

> = greater than
< = less than

Biological and Chemical Specifications

♂ = male
♀ = female
sp. = species (singular)
spp. = species (plural)
po = oral
rec = rectal
sc = subcutaneous
im = intramuscular
ip = intraperitoneal
iv = intravenous
RBC = red blood cell (erythrocyte)
WBC = white blood cell (leukocyte)
CNS = central nervous system
CSF = cerebrospinal fluid

d = *dextro* (rotatory)
l = *levo* (rotatory)
D = *dextro* (in configurational sense only)
L = *levo* (in configurational sense only)
m = meta
o = ortho
p = para
M = molar
N = normal, or *nitro*
O = *oxy*
S = *sulf* or *sulfo*
STP = standard temperature and pressure

INTRODUCTION

The *Biology Data Book* is a volume of broad scope and limited coverage designed to serve as a basic reference in the field of biology. It is a radical revision of the *Handbook of Biological Data* published in 1956 by the W. B. Saunders Company.

Much has been learned over the past eight years from users of the old handbook. In order to incorporate their suggestions for improvement, i.e., larger type, literature citations, and a detailed index, it became obvious that the number of tables to be included in the *Biology Data Book* would have to be restricted to a more discriminating selection. The Committee on Biological Handbooks assigned the task of choosing the basic tables for the new general reference book to a specially appointed *Biology Data Book* Advisory Committee. Copies of the old handbook and of the specialized volumes in the Biological Handbooks series were sent to the members of the Advisory Committee, who used these books for two years in daily work situations. On the basis of frequency of referral, the Advisory Committee selected 143 tables for extensive revision and updating, and recommended the inclusion of 12 additional tables containing data of fundamental importance and current relevance.

The space limitations affecting subject coverage also imposed restrictions on the number of species to be included in the *Biology Data Book*. The Advisory Committee approved a list of approximately 400 species, which included the more common animals and plants, certain physiologically unique forms, and the size extremes within taxonomic groups. Frequently data were not accessible for a plant or animal appearing on the list, but were available for a related form. In such cases, the information for the related organism was used in the tabulation. In the tables on toxins and parasitism, the inclusion of data was dependent on whether the victim or host, rather than the offending organism, appeared on the approved list.

The *Biology Data Book* has been organized in the form of quantitative and descriptive tables, charts, and diagrams, and arranged in 13 sections for the convenience of the user. Contents of the volume have been authenticated by 470 leading investigators in the fields of botany, zoology, and medicine. The review process to which the data have been subjected was designed to eliminate, insofar as possible, material of questionable validity and errors of transcription.

An explanatory headnote, serving as an introduction to the subject matter, may precede a table. More frequently, tables are prefaced by a short headnote containing such important information as units of measurement, abbreviations, definitions, and estimate of the range of variation. To interpret the data, reading of the related headnote is essential.

The main conventions used throughout the data book have been adapted from the *Style Manual for Biological Journals*, published in 1960 for the Conference of Biological Editors by the American Institute of Biological Sciences. The terminology has been checked against *Webster's Third New International Dictionary*, published in 1961 by G. & C. Merriam Company.

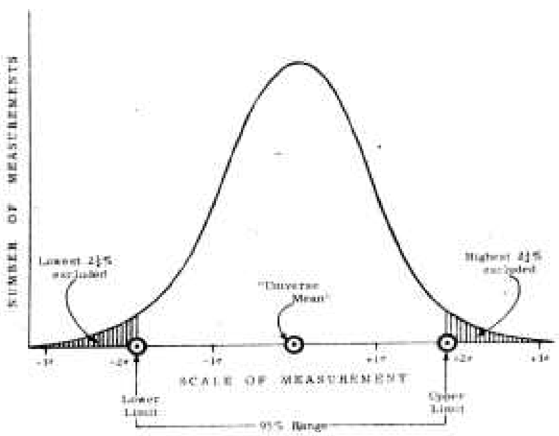
Appended to the tables are the names of the contributors, and a list of the literature citations arranged in alphabetical sequence. The reference abbreviations conform to the *1961 Chemical Abstracts List of Periodicals* published by the American Chemical Society.

It is suggested that the table of contents be used in conjunction with the index: the table of contents to determine the scope of the data for a particular topic, and the index to locate data for a specific subject or organism. To facilitate identification, the index includes the taxonomic orders for animals, and the family for plants.

. . . .

Values are generally presented as a mean and the lower and upper limit of the range of individual values about the mean. This range may be estimated in several ways, the method depending on the information available. Letter designations (a, b, c, d) identify types of ranges in descending order of accuracy.

(a) When the group of values is relatively large, a 95% range is derived by curve fitting. A recognized type of normal frequency curve is fitted to a group of measured values, and the extreme 2.5% of the area under the curve at each end is excluded *(see illustration)*.



(b) When the group of values is too small for curve fitting, as is usually the case, a 95% range is estimated by a simple statistical calculation. Assuming a normal symmetrical distribution, the standard deviation is multiplied by a factor of 2, then subtracted from and added to the mean to give the lower and upper range limits.

(c) A less dependable, but commonly applied, procedure takes as range limits the lowest value and the highest value of the reported sample group of measurements. It underestimates the 95% range for small samples and overestimates for larger sample sizes, but may be used in preference to the preceding method where there is marked asymmetry in the position of the mean within the sample range.

(d) Another estimate of the lower and upper limits of the range of variation is based on the judgment of an individual experienced in measuring the quantity in question. The trustworthiness of such limits should not be underestimated.

I. GENETICS AND CYTOLOGY

1. CHROMOSOME NUMBERS: ANIMALS

For information on additional species, consult references 2 and 26, Part I.

Part I. VERTEBRATES

Diploid (column C): s = spermatogonium; o = oogonium; m = somatic cell. **Haploid** (column D): ♂(I) = primary spermatocyte; ♂(II) = secondary spermatocyte.

	Species	Common Name	Chromosome Number Diploid	Chromosome Number Haploid	Sex Type	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
	Mammalia					
1	*Homo sapiens*	Man	46s, o, m	23♂(I, II)	X-Y♂	60
2	*Bos taurus*	Cattle	60m	...	X-Y♂	22,52
3	*Camelus bactrianus*	Bactrian camel	...	35♂(I)	...	39
4	*Canis familiaris*	Dog	78m	...	X-Y♂	3
5	*Capra hircus*	Goat	60s	30♂(I, II)	X-Y♂	22,23
6	*Cavia porcellus*	Guinea pig	64m	...	X-Y♂	3
7	*Dasypus novemcinctus*	Nine-banded armadillo	60m	...	X-O♂?	42,43
8	*Didelphis marsupialis virginiana*	Virginia opossum	22s, m	11♂(I, II)	X-Y♂	41
9	*Equus caballus*	Horse	64m	...	X-Y♂	52
10	*Erinaceus europaeus*	European hedgehog	48s	24♂(I)	X-Y♂	4,5
11	*Felis catus*	Cat	38m	...	X-Y♂	3
12	*Macaca mulatta*	Rhesus monkey	42	...	X-Y♂	7
13	*Mesocricetus auratus*	Golden hamster	44m	...	...	3
14	*Mus musculus*	House mouse	40s	20♂(I, II)	X-Y♂	20
15	*Mustela vison*	Mink	30	...	...	55
16	*Myotis myotis*	Common brown bat	44s	22♂(I)	X-Y♂	5
17	*Ondatra zibethica*	Muskrat	54s	...	...	27
18	*Ornithorhynchus anatinus*	Platypus	70±10s	...	...	33
19	*Oryctolagus cuniculus*	European rabbit	44s	22♂(I)	X-Y♂	23,33
20	*Ovis aries*	Sheep	54m	...	X-Y♂	34
21	*Phocaena dalli*	Dall's porpoise	44s	22♂(I, II)	X-Y♂	25
22	*Rattus norvegicus*	Norway rat	42m	...	X-Y♂	28
23	*Sciurus carolinensis*	Gray squirrel	48s	...	X-Y♂	8
24	*Sorex araneus*	European shrew	23s	11♂(I); 11,12♂(II)	X_1X_2-Y♂	4,5
25	*Sus scrofa*	Swine	40s	20♂(I, II)	X-Y♂	21,23
	Aves					
26	*Anas platyrhynchos*	Mallard duck	80s	40♂(I)	...	69
27	*Anser albifrons*	White-fronted goose	82s	41♂(I)	...	69
28	*Columba livia*	Street pigeon	80s, 79o	40♂(I)	X-X♂, X-O♀	70
29	*Cygnus cygnus*	Whooper swan	80s	...	...	69
30	*Gallus domesticus*	Chicken	78s, 77o	39♂(I)	X-X♂, X-O♀	66,67
31	*Larus crassirostris*	Black-tailed gull	64s	...	...	61
32	*Meleagris gallopavo*	Turkey	82s, 81o	41♂(I)	X-X♂, X-O♀	68
33	*Passer domesticus*	House sparrow	54-60s, m	23♂(I)?	X-X♂, X-O♀	46
34	*Phasianus colchicus*	Ring-necked pheasant	82s, 81o	41♂(I)	X-X♂, O♀	66
35	*Pica pica*	Black-billed magpie	82s, 81o	...	X-O♀	56
36	*Turdus merula*	Blackbird	60-85s,o,m	...	X-X♂, X-O♀	62
	Reptilia					
37	*Alligator mississipiensis*	American alligator	32s	16♂(I)	...	48
38	*Ancistrodon acutus*	Mexican copperhead	36s	18♂(I)	X-X♂	37
39	*Anguis fragilis*	Slowworm	44s, o	22♂(I)	X-Y♀?	30
40	*Anolis carolinensis*	American "chameleon"	36s	18♂(I, II)	X-X♂	32
41	*Caretta caretta*	Loggerhead turtle	58s, 57o	...	X-X♂, X-O♀	38
42	*Chrysemys marginata*	Painted turtle	...	17♂(I)	X-O♂	11
43	*Emys orbicularis*	European pond turtle	50s	25♂(I)	X-X♂	32
44	*Eumeces elegans*	Elegant skink	26s	...	...	29,35
45	*Heloderma suspectum*	Gila monster	38s	19♂(I, II)	X-X♂	31,32
46	*Naja naja*	Indian cobra	38s	19♂(I, II)	X-X♂	37
47	*Natrix tigrina*	Japanese water snake	40s	20♂(I, II)	X-X♂	36

continued

I. CHROMOSOME NUMBERS: ANIMALS

Part I. VERTEBRATES

	Species	Common Name	Chromosome Number		Sex Type	Reference
			Diploid	Haploid		
	(A)	(B)	(C)	(D)	(E)	(F)
	Reptilia					
48	*Sceloporus spinosus*	Spiny fence lizard	22s	11♂(I)	XX-O♂?	40
49	*Sphenodon punctatus*	Tuatara	36s	18♂(I, II)	....	12
50	*Sternotherus odoratus*	Musk turtle	50s	25♂(I, II)	....	47
51	*Thamnophis butleri*	Butler's garter snake	37s	18♂(I)	XX-Y♂?	59
	Amphibia					
52	*Ambystoma tigrinum*	Tiger salamander	28s	14♂(I)	X-O♂	6
53	*Amphiuma means*	Two-toed amphiuma	....	12♂(I, II)	....	14
54	*Bufo americanus*	American toad	....	11♂(I, II)	X-Y♂?	65
55	*Bufo arenarum*	Sand toad	22s	11♂(I, II)	....	50,51
56	*Cryptobranchus alleganiensis*	Hellbender	62s	31♂(I, II)	....	16
57	*Hyla arborea*	Tree frog	24s	12♂(I, II)	....	10,63
58	*Necturus maculosus*	Mud puppy	....	12♂(I)	....	13
59	*Rana catesbeiana*	American bullfrog	26s	13♂(I, II)	....	24
60	*R. pipiens*	Leopard frog	26s	13♂(I)	....	45
61	*Triturus cristatus*	Crested newt	24s	12♂(I)	....	63
62	*T. viridescens*	Common newt	22m	....	....	9
63	*Xenopus laevis*	Clawed frog	36s	....	....	63,64
	Pisces					
64	*Anguilla anguilla*	European freshwater eel	36s, o?	....	....	49
65	*Carassius auratus*	Goldfish	94s	47♂(I, II)	....	15,19
66	*Coregonus albula*	European lake whitefish	80m	....	....	57
67	*Cyprinus carpio*	Carp	104s	52♂(I, II)	....	15,18
68	*Esox lucius*	Northern pike	18m	....	....	58
69	*Fundulus heteroclitus*	Mummichog	45m	....	....	44
70	*Lepidosiren paradoxa*	South American lungfish	38m	19♂(I)	....	1
71	*Osmerus eperlanus*	European smelt	58m	....	....	57
72	*Perca fluviatilis*	European perch	28m	....	....	58
73	*Protopterus annectans*	West African lungfish	34s	17♂(I)	....	63
74	*Salmo salar*	Atlantic salmon	60m	30♂(I)	....	57
75	*S. trutta*	Brown trout	80m	40♂(I)	....	57
76	*Salvelinus fontinalis*	Eastern brook trout	84m	....	....	57
	Chondrichthyes					
77	*Raja meerdervoortii*	Skate	104s	52♂(I, II)	....	17
78	*Squalus suckleyi*	Pacific spiny dogfish	62s	31♂(I, II)	....	17
	Agnatha					
79	*Myxine glutinosa*	Atlantic hagfish	ca.52s, m	26♂(I, II)	....	53,54

Contributor: Makino, Sajiro

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continued

1. CHROMOSOME NUMBERS: ANIMALS

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Part II. INVERTEBRATES

Diploid (column D): s = spermatogonium; o = oogonium; m = somatic cell. **Haploid** (column E): ♂(I) = primary spermatocyte; ♂(II) = secondary spermatocyte; ♀(I) = primary oocyte; ♀(II) = secondary oocyte.

	Class	Species	Common Name	Chromosome Number		Reference
				Diploid	Haploid	
	(A)	(B)	(C)	(D)	(E)	(F)
			Chordata			
1	Cephalochordata[1]	*Branchiostoma lanceolatum*	Amphioxus	24o	12♀(I,II)	10
2	Ascidiacea	*Ciona intestinalis*	Sea squirt	18m	....	5
			Echinodermata			
3	Asteroidea	*Asterias forbesi*	Starfish	36m	18♂(I,II)	23
4	Echinoidea	*Arbacia punctulata*	Sea urchin	ca. 40m	....	68
5		*Echinarachnius parma*	Sand dollar	52m	....	36
6	Holothuroidea	*Stichopus regalis*	Sea cucumber	28-36s	16-18♂(I)	19
			Arthropoda			
7	Arachnida	*Ixodes ricinus*	Sheep tick	28s	....	46

/1/ Subphylum.

continued

1. CHROMOSOME NUMBERS: ANIMALS

Part II. INVERTEBRATES

	Class	Species	Common Name	Chromosome Number		Ref-er-ence
				Diploid	Haploid	
	(A)	(B)	(C)	(D)	(E)	(F)
			Arthropoda			
8	Arachnida	*Tegenaria domestica*	House spider	43s	23♂(I)	53
9	Merostomata	*Tachypleus tridentatus*	King crab	26s	13♂(I,II)	48
10	Crustacea	*Artemia salina*	Brine shrimp	42m	21♀(I,II)	1
11		*Astacus fluviatilis*	Crayfish	....	ca. 58♂(I)	52
12		*Cyclops viridis*	Cyclops	12o	6♀(I)	63
13		*Daphnia magna*	Water flea	20s,m	10♀(I)	40
14		*Homarus* sp.	Lobster	....	18♂(I)	31
15		*Lepas anatifera*	Goose barnacle	26s,o	13♂(I), 13♀(I)	75
16		*Potamon dehaanii*	River crab	82s	41♂(I,II)	77
17	Insecta	*Aedes albopictus*	Mosquito	6s,o	....	59
18		*Apis mellifera*	Honeybee	16o	16♂(I,II)	13,14
19		*Bombyx mori*	Silkworm	56s	28♂(I,II)	47
20		*Calliphora erythrocephala*	Bluebottle fly	12s,o	6♂(I,II)	24
21		*Cimex lectularius*	Bedbug	30-34s,33-41o	18-21♂(I)	11
22		*Ctenocephalides canis*	Dog flea	14♂m	....	25,26
23		*Drosophila melanogaster*	Fruit fly	8s,o	4♀(I)	20
24		*Dytiscus marginalis*	Diving beetle	38s	19♂(I,II)	55
25		*Ephestia kuehniella*	Mediterranean flour moth	....	30♂(I,II); 30♀(I); 29,30♀(II)	71
26		*Formica sanguinea*	Red ant	ca. 48m	24♀(I,II)	57
27		*Habrobracon juglandis*	Parasitic wasp	20o	10♀(I)	62
28		*Leptinotarsa signaticolis*	Potato beetle	34s	17♂(I); 16, 17♂(II)	74
29		*Locusta migratoria*	Migratory locust	23s	12♂(I); 11,12♂(II)	76
30		*Magicicada septendecim*	Periodical cicada	19s,20o	10♂(I); 9,10♂(II)	58
31		*Mantis religiosa*	Praying mantis	27s	13♂(I); 13,14♂(II)	27
32		*Melanoplus differentialis*	Differential grasshopper	24♀m	12♀(I,II)	60
33		*Musca domestica*	Housefly	12s,o	6♂(I,II)	65
34		*Pediculus capitis*	Head louse	12m	....	16
35		*Periplaneta americana*	American cockroach	33s, 34♀m	17♂(I); 16,17♂(II)	66
36		*Pieris brassicae*	European cabbageworm	30s,o	15♂(I,II), 15♀(I)	15
37		*Popillia japonica*	Japanese beetle	18s	9♂(I,II)	78
38		*Samia cynthia*	Cynthia moth	26s,o, ♀m	13♂(I,II), 13♀(I,II)	12
39		*Tenebrio molitor*	Yellow mealworm	20s,o, ♀m	10♂(I,II)	64
40		*Thermobia domestica*	Firebrat	34s, 36o	18♂(I); 16,18♂(II)	49
41	Onychophora	*Peripatus* sp.	Peripatus	28s,o,m	14♂(I,II)	39
			Annelida			
42	Hirudinea	*Herpobdella bistriata*	Leech	18s	9♂(II)	73
43	Oligochaeta	*Enchytraeus humicultor*	White worm	32s,o	16♀(I)	69
44		*Lumbricus terrestris*	Earthworm	36m	....	41
45	Polychaeta	*Nereis limbata*	Clam worm	20-30m	14♀(I)	3,4
			Mollusca			
46	Cephalopoda	*Sepia officinalis*	Cuttlefish	....	6♀(I)	35
47	Bivalvia	*Mactra* sp.	Bar clam	24m	12♀(I,II)	29
48		*Unio* sp.	Pearl mussel	....	16♀(I,II)	33
49	Gastropoda	*Aplysia limacina*	Sea hare	24m	....	67
50		*Doris bifida*	Sea lemon	32m	16♀(I,II)	61
51		*Helix pomatia*	Land snail	54s	27♂(I), 27♀(I)	50
52		*Lymnaea japonica*	Freshwater snail	36s	18♂(I)	22
			Aschelminthes			
53	Nematoda	*Ascaris lumbricoides*	Large roundworm	43s; 48o; 43, 48m	24♂(I); 19, 24♂(II); 24♀(I,II)	72
54		*Rhabditis* sp.	Free-living roundworm	13s; 14o; 13, 14m	7♂(I); 6,7♂(II); 7♀(I,II)	30
55	Rotifera	*Asplanchna intermedia*	Rotifer	24s, ♂m	12♂(I)	67
			Platyhelminthes			
56	Cestoda	*Taenia pisiformis*	Dog tapeworm	....	13-15♀(I)	70
57	Trematoda	*Fasciola hepatica*	Liver fluke	12o,m	6♀(I,II)	56

continued

1. CHROMOSOME NUMBERS: ANIMALS

Part II. INVERTEBRATES

	Class	Species	Common Name	Chromosome Number		Reference
				Diploid	Haploid	
	(A)	(B)	(C)	(D)	(E)	(F)
			Platyhelminthes			
58	Trematoda	*Schistosoma haematobium*	Human blood fluke	14s	8♂(I); 6,8♂(II); 8♀(II)	34
59	Turbellaria	*Planaria torva*	Flatworm	16m	8♀(I,II)	37,38
			Cnidaria			
60	Scyphozoa	*Aurelia flavedula*	Scyphomedusa	-20m	9-10♀(I)	21
61	Hydrozoa	*Gonionemus murbachii*	Hydromedusa	25s; ca. 24o,m	ca. 12♂(I,II)	2
62		*Hydra vulgaris attenuata*	Freshwater hydra	.o,m	16♂(I)	45
63		*Obelia geniculata*	Marine hydra		17♀(I)	18
			Porifera			
64	Desmospongiae	*Spongilla lacustra*	Freshwater sponge	10-12m	....	42,43
65	Calcarea	*Scypha ciliatum*	Marine sponge	26m	13♀(I)	17
			Protozoa			
66	Ciliata	*Didinium nasutum*	Carnivorous ciliate	16	8	51
67		*Stentor coeruleus*	Heterotrichous ciliate	28	14	44
68	Rhizopoda	*Amoeba proteus*	Free-living amoeba	ca. 50[a]		8
69		*Entamoeba histolytica*	Parasitic amoeba	6[a]		28
70	Mastigophora	*Euglena gracilis*	Green flagellate	ca. 45[a]		32
71		*Trypanosoma equiperdum*	Trypanosome	3[a]		54
72		*Volvox globator*	Pale-green flagellate	....	5	9

/a/ Uncertain whether diploid or haploid.

Contributor: Makino, Sajiro

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2. CHROMOSOME NUMBERS: PLANTS

For information on additional species of plants, consult reference 2, Part I.

Part I. NONVASCULAR

Many of the chromosome numbers are of doubtful accuracy since the small size of the chromosomes makes it difficult to determine exact counts.

	Class and Species	Haploid Number	Reference
	(A)	(B)	(C)
	Myxophyta		
	Myxomyceteae		
1	*Comatricha nigra*	ca. 30	70
2	*Physarum polycephalum*	ca. 90	49
	Acrasieae		
3	*Dictyostelium discoideum*	7	76,77
	Fungi		
	Phycomycetes		
4	*Phycomyces nitens*	2	43
5		ca. 12	9
6	*Saprolegnia ferax*	7 or more	25
	Ascomycetes		
7	*Aspergillus niger*	2	71,74
8	*Neurospora crassa*	7	39,63
9		9	35
10	*Penicillium* sp.	2	13
11	*Peziza vesiculosa*	8	18,22,44
12	*Saccharomyces cerevisiae*	2	6
13		4	15
14	*Schizosaccharomyces octosporus*	4	75
	Ascomycetes		
15	*Venturia inaequalis*	4-6	5
16		7	12,30
	Basidiomycetes		
17	*Agaricus campestris*	4	51,54
18		9	10
19		12	28
20	*Lycoperdon piriforme*	2	41
21		6	23
22	*Panus torulosus*	6	23
23	*Puccinia graminis*	2	50
24		6	40
25	*Ustilago hordei*	2	29,31,72,73
	Lichenes		
	Ascolichenes		
26	*Cladonia cristatella*	4	1
27	*Dermatocarpon fluviatile*	6-8	64
28	*Lecanora dispersa*	3	1
29	*Lecidea crustulata*	2	1
	Algae		
	Chrysophyta[1]		
30	*Vaucheria sessilis*	7-10	19

/1/ Division.

continued

2. CHROMOSOME NUMBERS: PLANTS

Part I. NONVASCULAR

	Class and Species	Haploid Number	Reference
	(A)	(B)	(C)
	Algae		
	Chlorophyta[1]		
31	*Acetabularia wettsteinii*	ca. 10	57
32	*Chlamydomonas moewusii*	8	8
33		36±2	55
34	*Cladophora glomerata*	32	36
35		48	56,59-61
36	*Oedogonium* spp.	9,13,17-19	67
37	*Spirogyra majuscula*	34-36	16
38	*Ulothrix zonata*	4	17,58
39		10	52,53
	Phaeophyta[1]		
40	*Ectocarpus siliculosus*	8	62
41		8,9	46
42	*Fucus vesiculosus*	10	14
43		32	78
44	*Laminaria digitata*	27-31	45
	Rhodophyta[1]		
45	*Polysiphonia nigrescens*	30	4
46	*Porphyra umbilicalis*	5	32

	Class and Species	Haploid Number	Reference
	(A)	(B)	(C)
	Bryophyta		
	Musci		
47	*Hylocomium splendens*	10	68
48		11	69
49		12	79
50	*Hypnum cupressiforme*	10	68
51		16	3
52	*Mnium undulatum*	6	24,27
53		7	42
54	*Polytrichum juniperinum*	7	3,34,80
55	*Sphagnum girgensohnii*	23	26
	Hepaticae		
56	*Marchantia polymorpha*	9-11	20,21
57	*Riccia fluitans*	8	7,66
58		16	38
	Anthocerotae		
59	*Anthoceros laevis*	4	11,33
60		5	47
61		6	48,65
62		8	37

/1/ Division.

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continued

2. CHROMOSOME NUMBERS: PLANTS

Part I. NONVASCULAR

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Part II. VASCULAR

For additional information on gymnosperms and angiosperms, consult reference 18.

	Species (Common Name)	Diploid Number	Reference
	(A)	(B)	(C)
	Pteridophyta		
1	*Adiantum pedatum* (American maidenhair)	58	48
2	*Equisetum arvense* (field horsetail)	216	8
3	*Lycopodium clavatum* (club moss)	68	8
4	*Polypodium virginianum* (rock polypody)	74,148	8,48
5	*Selaginella selaginoides* (spike moss)	18	8
	Gymnospermae		
6	*Abies concolor* (white fir)	24	67
7	*Cupressus sempervirens* (Italian cypress)	22	51
8	*Ginkgo biloba* (ginkgo)	24	45
9	*Juniperus virginiana* (eastern red cedar)	22,33	74
10	*Larix occidentalis* (western larch)	24	67
11	*Picea glauca* (white spruce)	24	67
12	*Pinus palustris* (longleaf pine)	24	49
13	*Sequoia gigantea* (giant sequoia)	22	39
14	*Taxodium distichum* (bald cypress)	22	73
15	*Taxus baccata* (English yew)	24	12
16	*Thuja occidentalis* (northern white cedar)	22	67
17	*Tsuga canadensis* (eastern hemlock)	24	67
	Angiospermae (Monocotyledoneae)		
18	*Allium cepa* (garden onion)	16,32	11
19	*Asparagus officinalis* (garden asparagus)	20	55
20	*Avena sativa* (common oat)	42	22
21	*Elodea canadensis* (Canada waterweed)	48	65
22	*Gladiolus* spp.[1] (gladiolus)	30,45,60,75	2
23	*Hordeum vulgare* (barley)	14	42
24	*Iris versicolor* (blue-flag iris)	72,84,105	68
25	*Lilium* spp. (lily)	24	29,64
26	*Oryza sativa* (rice)	24	1
27	*Phleum pratense* (timothy)	42	54
28	*Phoenix dactylifera* (date palm)	36	4
29	*Poa pratensis* (Kentucky	36-123	56
30	bluegrass)	38-96	40
31	*Tradescantia virginiana* (Virginia spiderwort)	24	14
32	*Triticum aestivum* (wheat)	42	61
33	*Yucca* spp. (yucca)	60	72,82
34	*Zea mays* (corn)	20	60
	Angiospermae (Dicotyledoneae)		
35	*Acer saccharinum* (silver maple)	52	77

/1/ Cultivated.

continued

2. CHROMOSOME NUMBERS: PLANTS

Part II. VASCULAR

	Species (Common Name)	Diploid Number	Reference
	(A)	(B)	(C)
	Angiospermae (Dicotyledoneae)		
36	*Alnus rubra* (red alder)	28	83
37	*Antirrhinum majus* (snapdragon)	16	59
38	*Beta vulgaris* (common beet)	18	47,84
39	*Betula lenta* (sweet birch)	28	86
40	*Capsicum frutescens* (bush red pepper)	24	69
41	*Carya tomentosa* (mockernut hickory)	64	85
42	*Catalpa speciosa* (northern catalpa)	40	70
43	*Chrysanthemum maximum* (Pyrenees chrysanthemum)	85,90,126,148, 154,160,171	21
44	*Cinchona ledgeriana* (ledger-bark cinchona)	34	19
45	*Citrus limon* (lemon)	18,36	44
46	*C. sinensis* (sweet orange)	45	44
47	*Cornus florida* (flowering dogwood)	22	20
48	*Cucumis sativus* (cucumber)	14	30
49	*Cucurbita pepo* (pumpkin)	40	10,23
50	*Daucus carota* (carrot)	18	26,31
51	*Digitalis purpurea* (common foxglove)	56	9
52	*Fagopyrum esculentum* (buckwheat)	16	36
53	*Fagus sylvatica* (European beech)	24	38
54	*Fragaria virginiana* (Virginia strawberry)	56	33
55	*Fraxinus americana* (white ash)	46,92,138	87
56	*Glycine soja* (soybean)	40	62
57	*Gossypium hirsutum* (upland cotton)	52	89
58	*Helianthus annuus* (common sunflower)	34	27
59	*Ilex aquifolium* (English holly)	40	50
60	*Ipomoea batatas* (sweet potato)	90	80
61	*Juglans nigra* (black walnut)	32	85
62	*Lactuca sativa* (lettuce)	18	79
63	*Lycopersicon esculentum* (tomato)	24	3
64	*Magnolia* spp. (magnolia)	38,76,114	34
65	*Malus pumila* (common apple)	34,51	16
66	*Medicago sativa* (alfalfa)	16	6
67		32,64	81
68	*Nicotiana tabacum* (common tobacco)	48	28
69	*Oenothera biennis* (common evening primrose)	14	16
70	*Pastinaca sativa* (parsnip)	22	57
71	*Persea americana* (American avocado)	24	7
72	*Phaseolus vulgaris* (kidney bean)	22	78
73	*Phlox* spp. (phlox)	14,21,28	24,25,53
74	*Pisum sativum* (garden pea)	14	63
75	*Populus tremuloides* (quaking aspen)	38	71
76	*Prunus amygdalus* (almond)	16	15
77	*P. domestica* (garden plum)	48	15
78	*P. persica* (peach)	16	15
79	*Pyrus communis* (pear)	34,51	17
80	*Quercus alba* (white oak)	24	75
81	*Raphanus sativus* (garden radish)	18	41
82	*Rheum officinale* (medicinal rhubarb)	22	37
83	*Rhododendron* spp. (rhododendron)	26,39,52,78, 104,156	35
84	*Ribes* spp. (currant)	16	13,52,90
85	*Rosa* spp.[1] (rose)	14,21,28	88
86	*Salix alba* (white willow)	76	5
87	*Solanum tuberosum* (potato)	48	76
88	*Trifolium pratense* (red clover)	14	46
89	*Ulmus americana* (American elm)	28	43
90		56	66
91	*Vicia faba* (broad bean)	12,14	32
92	*Vitis vinifera* (European grape)	38,57,76	58

/1/ Cultivated.

Contributors: (a) Darlington, C. D., (b) Morton, C. V., (c) Sax, Karl

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3. SEX LINKAGE: MAN

For additional information, consult reference 23.

	Mutation	Phenotypic Expression: Hemizygote $\overline{X}Y$	Phenotypic Expression: Heterozygote $\overline{X}X$	Phenotypic Expression: Homozygote $\overline{XX}$	Reference
	(A)	(B)	(C)	(D)	(E)
1	Agammaglobulinemia	Gamma globulin absent	Absent	Unknown	18
2	Albinism, ocular	Melanin absent from eye	Mosaic pigmentary pattern of fundus oculi	Unknown	39
3	Aldrich syndrome	Eczema, thrombocytopenia	Absent	Unknown	1
4	Amelogenesis imperfecta	Defective enamel of teeth	Defective enamel in some families	Unknown	15,44
5	Anemia, hypochromic (Rundles, Falls)	Anemia	Splenomegaly, minor red cell change	Unknown	30
6	Angiokeratoma, diffuse	Dermal, vascular, neural, and renal lesions	Mild involvement	Unknown	43
7	Atrophy, peroneal	Atrophy of calf muscles	Occasional manifestation	Unknown	2
8	Blood group Xg^a	Erythrocytes agglutinate with antiserum	Erythrocytes agglutinate with antiserum	Erythrocytes agglutinate with antiserum	24
9	Choroideremia	Night blindness, constricted visual fields, blindness	Depigmented retina	Unknown	21
	Color blindness, partial				
10	Deutan series	Red blindness	Defect in only a few	Red blindness	10
11	Protan series	Green blindness	Mild defect revealed by special tests	Green blindness	10
12	Deaf-mutism	Profound deafness at birth	Absent	Profound deafness at birth	26,32
13	Diabetes insipidus, nephrogenic	High urinary output unaffected by pitressin	Slight increase in urinary output	Unknown	40
	Dysplasia				
14	Anhidrotic ectodermal	Widespread ectodermal defects	Patchy defect	Unknown	9
15	Spondylo-epiphyseal	Dwarfism, with changes especially of spine and hips	Absent	Unknown	17
	Dystrophy				
16	Macular	Loss of central vision	Absent	Unknown	34
17	Muscular (Duchenne)	Progressive atrophy of muscles	Mild serum enzymatic changes	Unknown	7,36
18	Glucose-6-PO_4 dehydrogenase deficiency	Hemolytic anemia with drugs	Absent	Hemolytic anemia with drugs	6
19	Hemeralopia	Night blindness with myopia	Absent	Unknown	34
	Hemophilia				
20	Classical[1]	Severe bleeder	Absent	Severe bleeder	5,16,25, 33
21	Mild[2]	Mild bleeder	Slight occasional manifestation	Unknown	14
22	Hurler syndrome	Dwarfism, mucopolysaccharide deposits, mental deficiency	Absent	Unknown	22
23	Hydrocephalus, congenital	Stenosis of aqueduct of Sylvius	Absent	Unknown	11
24	Hypoparathyroidism	Low serum Ca^{++}, tetany	Absent	Unknown	27
25	Hypophosphatemia	Low serum inorganic phosphorus	Low serum inorganic phosphorus	Unknown	42
26	Ichthyosis simplex	Scaly skin	Absent	Scaly skin	9
27	Idiocy	Idiocy with microcephaly	Absent	Unknown	3
28	Keratosis follicularis (Laméris)	Multiple horny skin growths	Absent	Unknown	9
29	Lowe's syndrome	Glaucoma, mental retardation, renal tubule defect	Absent	Unknown	37
30	Megalocornea	Large cornea	Occasional manifestation	Unknown	13
31	Microphthalmia	Abnormally small eyes and blindness	Absent	Absent	28
32	Nystagmus	Severe involuntary movement of eyeball	Slight involuntary movement of eyeball	Unknown	29,34
33	Ophthalmoplegia	Paralysis of eye muscles, myopia; knee jerks absent	Knee jerks absent	Unknown	31

/1/ Gene symbol = *h*. /2/ Gene symbol = h^m.

continued

3. SEX LINKAGE: MAN

	Mutation	Phenotypic Expression			Reference
		Hemizygote $\bar{X}Y$	Heterozygote $\bar{X}X$	Homozygote $\bar{X}\bar{X}$	
	(A)	(B)	(C)	(D)	(E)
34	Paraplegia, spastic	Spastic paralysis of legs	Absent	Unknown	19
35	Plasma thromboplastin component deficiency	Severe bleeder	Slight manifestation	Unknown	4,20
36	Retinal detachment, congenital	Retinal detachment and blindness	Absent	Blindness[3]	8,35,41
37	Retinitis pigmentosa	Choroidoretinal degeneration	Tapetal reflex	Unknown	12
38	Sclerosis, diffuse cerebral (Pelizaeus-Merzbacher)	Severe central nervous system involvement	Absent	Unknown	38

/3/ Questionable.

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4. LINKAGE GROUPS: VERTEBRATES

The size or length of a linkage map reflects the extent of genetics investigation rather than the number of genes possessed by the animal. Capital letters (in columns giving Gene Symbol, Linkage, and Mutation) indicate dominant genes.

Part I. GUINEA PIG

Cavia porcellus has 32 pair of chromosomes (±1 pair), including an XY pair in males. Linkage groups have been found for 2 pair.

	Gene Symbol	Linkage	Recombination Percentage	Mutation	Phenotypic Expression	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
	Linkage Group I					
1	*R*	*R--Px*	43.8±1.6	Rough fur	Rough fur, at least on hind toes	1-4
2	*Px*	*Px--R*	43.8±1.6	Pollex	Tendency to atavistic return of thumb, little toe, and, on rare occasions, big toe	
	Linkage Group II					
3	*si*	*si--m*	21.7±5.2	silvered (stationary from birth)	Silver-coated fur; incomplete recessive	5
4	*m*	*m--si*	21.7±5.2	modifier	Modifies rough fur effect; homozygote high-grade roughness	

Contributor: Wright, Sewall

References: [1] Castle, W. E., and A. Forbes. 1906. Carnegie Inst. Wash. Publ. 49:3. [2] Wright, S. 1928. Genetics 13:508. [3] Wright, S. 1941. Ibid. 26:650. [4] Wright, S. 1949. J. Exptl. Zool. 112:303. [5] Wright, S. 1959. Genetics 44:387.

Part II. MOUSE

Mus musculus has 20 pair of chromosomes; linkage groups have been found for 19 pair.

	Gene Symbol	Linkage	Recombination Percentage	Mutation	Phenotypic Expression	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
	Linkage Group I					
1	*fr*	*fr--sh-1*	16	frizzy	Fine thin hair, curled vibrissae	31
2	*ol* [1]	*ol--c*	17	oligodactyly	Reduced number of digits	48
3	*H-1*	*H-1--c*	7	Histocompatibility-1	Susceptibility to tissue transplants	91,93
4	*Hb* [1]	*Hb--c*	5[2], 2[3]	Hemoglobin pattern	Electrophoretic pattern of hemoglobin	76
5	*sh-1*	*sh-1--c*	4[2], 3[3]	shaker-1	Circling, head shaking, deafness	31,45,46
6	*c*	*c--p*	16[2], 12[3]	albino	Absence of pigment in hair and eyes	31,45,46, 76
7	*hf*	*c--hf*	3	hepatic fusion	Fusion of left median and left lateral lobes of liver	4
8	*tp*	*tp--p*	5	taupe	Reduced pigment in coat	79
9	*H-4* [1]	*H-4--p*	0	Histocompatibility-4	Susceptibility to tissue transplants	93
10	*p*	*hf--p*	13	pink-eyed dilution	Pink eyes, reduced black or brown pigment	4
11	*qv*	*p--qv*	12	quivering	Locomotor instability, pronounced trembling in adults, priapism in old males	103
12		*p--da*	17	dark	Darkens back of agouti or yellow mice	28
13	*pu*	*p--pu*	22	pudgy	Tail short or absent, torso shortened	81
	Linkage Group II					
14	*lu*	*lu--dse*	17	luxoid	Tibial hemimelia and preaxial polydactyly	44
15	*d*	*d--se*	0.1	dilute	Clumped pigment granules in hair	39
16	*se* [1]	*dse--du*	20	short ear	Reduced cartilaginous skeleton	44,90

/1/ Listed order not established. /2/ For heterozygous females. /3/ For heterozygous males.

continued

4. LINKAGE GROUPS: VERTEBRATES

Part II. MOUSE

	Gene Symbol	Linkage	Recombination Percentage	Mutation	Phenotypic Expression	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
				Linkage Group II		
17	*sv* [1]	*se--sv*	1	Snell's waltzer (recessive)	Circling, head shaking	43
18	*tk* [1]	*dse--tk*	11	tail kinks	Kinky tail, abnormal cervical and upper thoracic vertebrae	29
19	*du*	*du--dse*	20	ducky	Waddling gait	44,90
				Linkage Group III		
20	*pn*	*pn--s*	30	pugnose	Frontal and nasal bones short and wide	53
21	*s* [4]	*s--hr*	8	piebald	Unpigmented areas of fur	87
22	*ag* [1]	*ag--hr*	0	agitans	Impaired locomotion, tremor, death at 3-4 wk	49
23	*hr*	*hr--W*	42	hairless	Hair shed beginning at 10-14 da	38
24	*wl* [1,5]	*hr--wl*	4	wabbler-lethal	Impaired locomotion, death at 3-4 wk	59
25	*pi*	*hr--pi*	36	pirouette	Circling, head shaking, deafness	18
26	*W*	*pi--W*	7	Dominant spotting	White spotting and dilution of coat color, macrocytic anemia, sterility	17
27	*Ph* [1]	*W--Ph*	0.1	Patch	White spotting	47
28	*le* [1]	*W--le*	12	light ears	Dilution of coat color	58
29	*lx*	*W--lx*	18	luxate	Tibial hemimelia, preaxial polydactyly	7
30	*rl*	*lx--rl*	16	reeler	Impaired locomotion, death at 3-4 wk	24
				Linkage Group IV		
31	*r*	*r--si*	15	rodless retina	Absence of rods	52
32	*si*	*si--pg*	close	silvered	Absence or reduction of pigment in coat	30
33	*pg* [1]	*pg--si*	close	pigmy	Small size	30
34	*av* [1]	*si--av*	33	Ames' waltzer (recessive)	Circling, head shaking	83
				Linkage Group V		
35	*Ra*	*Ra--a*	22	Ragged	Thin coat	11,60,72
36	*Op*	*Op--a*	27	Opossum	Very thin coat; probably an allele of *Ra*	40
37	*H-3* [1]	*H-3--a*	10	Histocompatibility-3	Susceptibility to tissue transplants	91
38	*kr*	*kr--a*	1	Kreisler (recessive)	Circling, head shaking, deafness	48,58
39	*bp*	*bp--a*	0.3	brachypodism	Short feet	77
40	*a*	*a--un*	5	non-agouti	Removes yellow band from hairs	5,35
41	*un*	*un--we*	7[2], 5[3]	undulated	Wavy tail and abnormal vertebral column	26,35
42	*we*	*we--pa*	4[2], 2[3]	wellhaarig	Wavy coat and vibrissae	26,35,58
43	*mg* [1]	*a--mg*	13[2], 10[3]	mahogany	Dark coat, especially ears and tail	60
44	*pa*	*pa--ro*	1	pallid	Pink eyes, reduction of pigment in coat, frequent absence of otoliths	26
45	*ro*	*a--fi*	36[2], 27[3]	rough	Air spaces in hair abnormal, waved vibrissae	9,97
46	*dm* [1]	*a--dm*	13	diminutive	Small size, malformed vertebrae and ribs	95
47	*fi*	*pa--fi*	19	fidget	Circling, head shaking, occasional polydactyly	6
48	*Sd*	*fi--Sd*	22	Danforth's short tail	Short tail, urogenital abnormalities	97
				Linkage Group VI		
49	*N*	*N--Ca*	1[2], 3[3]	Naked	Hair breaks off near skin level	12,66,69
50	*Ca*	*Ca--bt*	4[2], 11[3]	Caracul	Wavy coat and vibrissae	66,69
51	*hl*	*Ca--hl*	2[2], 6[3]	hair-loss	Loses hair, usually naked by 2-3 mo	50
52	*Ht* [1]	*Ca--Ht*	2[2], 3[3]	High tail	Tail emerges high, short and thick at base, not kinked	80,81
53	*bt*	*hl--bt*	9	belted	White belt	50
				Linkage Group VII		
54	*Re*	*Re--Al*	7	Rex	Wavy coat and vibrissae	14,58
55	*Al*	*Al--sh-2*	21	Alopecia	Hair thin and patchy beginning at 1 or 2 mo	58
56	*ti* [1,6]	*Re--ti*	20[2], 21[3]	tipsy	Muscular incoordination, rabbit-like gait	84
57	*Tr* [7]	*Re--Tr*	23	Trembler	Convulsions in young, head trembling in adults	32

/1/ Listed order not established. /2/ For heterozygous females. /3/ For heterozygous males. /4/ *s--W* recombination, 47% [33]. /5/ *wl--W* recombination, 43% [59]. /6/ *ti--vt* recombination, 9% [84]. /7/ *Tr--sh-2* recombination, 3% [32].

continued

Part II. MOUSE

	Gene Symbol	Linkage	Recombination Percentage	Mutation	Phenotypic Expression	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
				Linkage Group VII		
58	*sh-2*[4]	*Re--sh-2*	28[2], 19[3]	shaker-2	Circling, head shaking, deafness	10,23,70
59	*vt*[1,5]	*Re--vt*	27[2], 18[3]	vestigial	Tail short or absent	67
60	*wa-2*	*vt--wa-2*	23	waved-2	Wavy coat and vibrissae	68
61	*Tm*[1]	....	....	Pulmonary tumors	Susceptibility to spontaneous and induced pulmonary tumors	96
				Linkage Group VIII		
62	*m*	*m--Pt*	3	misty	Dilute coat color, tail and belly spots	55
63	*Pt*	*Pt--b*	5	Pintail	Short tail	51,55
64	*b*	*m--b*	5	brown	Brown instead of black pigment	86,100
65	*an*[1]	*b--an*	5	anemia	Macrocytic anemia throughout life	48
66	*vc*	*b--vc*	7	vacillans	Muscular incoordination	85,86
67	*wi*[1]	*b--wi*	6	whirler	Circling, head shaking	55
68	*wd*	*b--wd*	31	waddler	Swaying of hindquarters during locomotion	102
				Linkage Group IX		
69	*T*	*T--Fu*	4	Brachyury	Short tail	2,20-22
70	*Fu*	*Fu--tf*	1	Fused	Tail and vertebral abnormalities	19
71	*tf*[1]	*T--tf*	8	tufted	Successive waves of hair loss and regrowth from anterior to posterior	65
72	*H-2*	*Fu--H-2*	4	Histocompatibility-2	Susceptibility to tissue transplantation	1,2,89
				Linkage Group X		
73	*v*	*v--ji*	18	waltzer	Circling, head shaking, deafness	88
74	*ji*	*ji--v*	18	jittery	Muscular incoordination, death at 3-4 wk	88
				Linkage Group XI		
75	*tc*[1]	*tc--mi*	8	truncate	Short tail, often with intermediate vertebrae of tail or sacrum missing	57
76	*mi*	*mi--px*	3	microphthalmia	Reduced pigment, failure of bone resorption	8
77	*px*	*px--wa-1*	1	postaxial hemimelia	Postaxial side of limbs defective	8
78	*wa-1*	*wa-1--Lc*	8	waved-1	Waved hair and vibrissae	75
79	*Lc*	*mi--wa-1*	11	Lurcher	Swaying of hindquarters and falling to one side	3
80	*ob*[1]	*mi--ob*	29	obese	Obesity with hyperglycemia	16
				Linkage Group XII		
81	*ru*	*ru--je*	49	ruby eye	Reduced pigmentation of eyes and hair	15,27,37, 98
82	*je*	*je--ru*	49	jerker	Circling, head shaking, deafness	15,27,39, 98
				Linkage Group XIII		
83	*Lp*	*Lp--ln*	38[2], 35[3]	Loop tail	Looped tail, abnormal behavior	94
84	*py*	*py--ln*	38[2], 24[3]	polydactyly	Preaxial polydactyly	34,71
85	*dr*[1]	*dr--Dh*	22	dreher	Circling, head shaking	63
86	*Dh*	*Dh--ln*	2	Dominant hemimelia	Preaxial hemimelia, absence of spleen	63
87	*ln*	*ln--Sp*	5	leaden	Clumped pigment granules in hair	71,94
88	*th*[1]	*th--ln*	5	tilted head	Head tilted to right or left side	61
89	*Sp*	*Sp--fz*	40[2], 33[3]	Splotch	White spotting on belly, feet, and tail	71,94
90	*fz*	*ln--fz*	43[2], 36[3]	fuzzy	Thin wavy hair and vibrissae	71,94
				Linkage Group XIV		
91	*cr*	*cr--ch*	15	crinkled	Absence of guard hairs and zigzags	54,74
92	*ch*	*ch--f*	18	congenital hydrocephalus	Severe reduction in cartilaginous skeleton	54,74
93	*f*	*f--ch*	18	flexed tail	Anemia at birth, flexed tail, belly spot	54,74

/1/ Listed order not established. /2/ For heterozygous females. /3/ For heterozygous males. /4/ *sh-2--wa-2* recombination, 24% for heterozygous females and 30% for heterozygous males [10,14,36,92,101]. /5/ *sh-2--vt* recombination, 2% [68].

continued

4. LINKAGE GROUPS: VERTEBRATES

Part II. MOUSE

	Gene Symbol (A)	Linkage (B)	Recombination Percentage (C)	Mutation (D)	Phenotypic Expression (E)	Reference (F)
				Linkage Group XV		
94	Tw	Tw--ax	0	Twirler	Circling, head shaking	62
95	ax	ax--Tw	0	ataxia	Muscular incoordination, death at 3-4 wk	62
				Linkage Group XVI		
96	Va	Va--de	28	Varitint-waddler	Dilute and spotted coat, circling, head shaking, deafness	13
97	de	de--Va	28	droopy ear	Ears set low on head, pinnae project laterally	13
				Linkage Group XVII		
98	sa	sa--bg	9	satin	Silky hair texture with high sheen	82
99	bg	bg--sa	9	beige	Diluted coat color	82
				Linkage Group XVIII		
100	Hk	Hk--Os	17	Hook	Short tail, anus displaced toward tail	42
101	Os	Os--tg	0	Oligosyndactylism	Digits reduced in number and fused	41
102	tg /1/	tg--Os	0	tottering	Wobbly gait, occasional convulsions	41
				Linkage Group XX (Sex Chromosome)		
103	Bn	Bn--Ta	12	Bent	Short crooked tail	73
104	Gy /1/	Gy--Ta	close	Gyro	Circling; abnormal development of long bones and ribs in males	64
105	Ta	Ta--Mo	4	Tabby	Dark transverse stripes	25,26
106	Blo	Ta--Blo	3	Blotchy	Irregular patches of light fur, males viable	78
107	Mo	Mo--Ta	4	Mottled	Patches of light hair, males die in utero	25,26
108	To /1/	Bn--To	22	Tortoise	Like Mo; possibly an allele	56
109	jp	Ta--jp	20	jimpy	Muscular incoordination, death at 3-4 wk	73
110	sf /1/	Ta--sf	44	scurfy	Scaliness, tight skin, death at 3-4 wk	99

/1/ Listed order not established.

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Part III. RABBIT

Oryctolagus cuniculus has 22 pair of chromosomes; linkage groups have been found for 6 pair. For additional information, consult references 7-9, 12.

	Gene Symbol (A)	Locus (B)	Mutation (C)	Phenotypic Expression (D)	Reference (E)
				Linkage Group I	
1	*c*	0	albinism	Coat color alleles vary from chinchilla to complete albinism	1,2,5
2	*y*	14.4	yellow fat	Yellow fat	3,11
3	*b*	42.8	brown	Brown coat	3,11

continued

4. LINKAGE GROUPS: VERTEBRATES

Part III. RABBIT

	Gene Symbol	Locus	Mutation	Phenotypic Expression	Reference
	(A)	(B)	(C)	(D)	(E)
				Linkage Group II	
4	*du*	0	dutch pattern	White belt on colored background	3,11
5	*En*	1.2	English	Colored spots on white background	1,4,6
6	*l*	14.3	angora hair	Increase in hair fiber length	1,4
				Linkage Group III	
7	r_1	0	rex_1	Short, plushlike coat	3,11
8	r_2	17.2	rex_2	Short, plushlike coat	2,4
				Linkage Group IV	
9	*a*	0	non-agouti	Black coat	3,11
10	*dw*	14.7	dwarf	Small size, lethal shortly after birth	3,11
11	*w*	29.9	wide-banded agouti	Wide banding of agouti hairs	5,10
				Linkage Group V	
12	*br*	0	brachydactyly	Abnormality of toes	11
13	*f*	28.3	furless	Fur restricted to extremities	5
14	*an*	36.8	erythrocyte agglutination	Erythrocytes agglutinate	14
				Linkage Group VI	
15	*E*	0	Extension	Extension of dark pigment	11
16	*At*	26.2	Production of atropinesterase	Production of atropinesterase	13

Contributors: (a) Sawin, Paul B., (b) Novitski, E.

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Part IV. RAT

Rattus norvegicus has 21 pair of chromosomes; linkage groups have been found for 5 pair. Seven genes have been found to be independent of linkage groups I-V, and of each other, and are provisionally regarded as markers of 7 additional chromosome pair: jaundice *(j)*, curly coat *(Cu_2)*, cataract *(Ca)*, blue dilution of coat *(d)*, hooded coat pattern *(h)*, cowlick *(cw)*, and shaker *(sr)*. [3, 5, 6, 9, 10]

	Gene Symbol	Locus	Mutation	Phenotypic Expression	Reference
	(A)	(B)	(C)	(D)	(E)
				Linkage Group I	
1	*p*	0	pink eye	Coat yellow, eyes pink	1, 2, 7, 14
2	*r*	20.5	red-eyed yellow	Coat yellow, eyes red	
3	*c*	21	albinism	Absence of pigment from coat and eyes	
4	*l*	24.3	lethal	Skeletal abnormalities	
5	*w*	66.3	waltzing	Runs in circles	
				Linkage Group II	
6	*Sh*	0	Shaggy	Hair and vibrissae curved	2, 7-9, 13
7	*Cu*	4	Curly	Hairs of coat and vibrissae curved	

continued

4. LINKAGE GROUPS: VERTEBRATES

Part IV. RAT

	Gene Symbol (A)	Locus (B)	Mutation (C)	Phenotypic Expression (D)	Reference (E)
			Linkage Group II		
8	*an*	14.3	anemia	Lack of erythrocytes; young anemic	2, 7-9, 13
9	*in*	28	incisorless	Incisors lacking	
10	*s*	47	silvered	Coat silvered	
11	*b*	52	brown	Black pigment of coat and eyes replaced by brown	
			Linkage Group III		
12	*n*	0	naked	Naked except for short fuzzy coat	2, 4, 12
13	*hr*	34.7	hairless	Hair lost at approximately 4 wk	
14	*wo*	75	wobbly	Ataxic locomotion	
			Linkage Group IV		
15	*k*	0	kinky	Hairs of coat and vibrissae kinky	2, 8
16	*st*	34.1	stub	Short stubby tail	
			Linkage Group V		
17	*A*	0	Agouti	Fur color agouti, wild type	2,11
18	*f*	44.6	fawn	Coat tawny blue to fawn	

Contributors: (a) Castle, W. E., (b) Novitski, E.

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Part V. CHICKEN

Gallus domesticus has 39 pair of chromosomes; linkage groups have been found for 6 pair (groups IV and V may eventually be joined).

	Gene Symbol (A)	Linkage (B)	Recombination Percentage (C)	Mutation (D)	Phenotypic Expression (E)	Reference (F)
			Linkage Group I (Sex Chromosome)			
1	*ko*	*ko--B*	13	head streak in down	Head streak in down	1,2
2	*B*	*B--Id*	10	Barring	Barring of feathers	
3	*Sd*	*B--Sd*	<1	Dilution	Dilution to blue	
4	*Id*	*Id--br*	27	Inhibitor	Inhibits melanin in dermis	
5	*br*	*br--Li*	10	brown eyes	Brown eyes	
6	*Li*	*Li--S*	16	Light down	Light down in chicks not black	
7	*S*	*S--al*	1.2	Silver	Silver plumage color	
8	*al*	*al--K*	1.6	albinism	Incomplete albinism	
9	*K*	*K--dw*	6.6	Slow feathering	Slow feathering	
10	*dw*	*dw--S*	7	dwarf	Small size	
11	*px*	*al--px*	11	paroxysm	Lethal	
12	*n*	*px--n*	6	naked	Without feathers	
13	*sh*	*n--sh*	14	shaker	Lethal nervous disorder	
14	*xl*/1/			lethal	Death at 3 wk	
15	*j*/1/			jittery	Lethal nervous disorder	

/1/ Listed order not established.

continued

4. LINKAGE GROUPS: VERTEBRATES

Part V. CHICKEN

	Gene Symbol	Linkage	Recombination Percentage	Mutation	Phenotypic Expression	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
			Linkage Group II			
16	*Cp*	*Cp--R*	0.4	Creeper	Achondroplasia	1
17	*R*	*R--U*	30	Rose comb	Rose comb	
18	*U*	*U--R*	30	Uropygial	Bifurcation of uropygial papilla	
			Linkage Group III			
19	*fr*	*fr--Cr*	46	fray	Defective wing and tail feathers	1,3
20	*Cr*	*Cr--I*	12.5	Crest	Topknot and cerebral hernia	
21	*I*	*I--F*	17	Dominant white	White plumage	
22	*F*	*F--I*	17	Frizzling	Recurved feathers	
			Linkage Group IV			
23	*O*	*O--P*	5	Blue egg	Eggshell blue	1
24	*P*	*P--ma*	33	Pea comb	Pea comb	
25	*ma*	*ma--Na*	46	marbling	Pattern in down of chick	
26	*Na*	*Na--ma*	46	Naked neck	Pterylae reduced	
			Linkage Group V			
27	*Na*	*Na--h*	43	Naked neck	Pterylae reduced	3
28	*h*	*h--Fl*	11	silkie	Barbules lack hooklets	
29	*Fl*	*Fl--h*	11	Flightless	Remiges break off	
			Linkage Group VI			
30	*D*	*D--M*	26	Duplex comb	Bifurcation of comb	1,3
31	*M*	*M--Po*	33	Multiple spurs	Multiple spurs	
32	*Po*	*Po--M*	33	Polydactyly	Supernumerary digits	

Contributor: Hutt, F. B.

References: [1] Hutt, F. B. 1949. Genetics of the fowl. McGraw-Hill, New York. [2] Hutt, F. B. 1960. Heredity 15:97. [3] Warren, D. C. 1949. Genetics 34:333.

5. LINKAGE GROUPS: INVERTEBRATES

The size or length of a linkage map reflects the extent of genetics investigation rather than the number of genes possessed by the insect. Capital letters (in columns giving Gene Symbol, Linkage, and Mutation) indicate dominant genes.

Part I. FRUIT FLY—

Drosophila melanogaster has 4 pair of chromosomes; linkage groups have been found for all 4 pair. For information on other species of *Drosophila*, consult the following references: *D. affinis* [30, 39], *D. ananassae* [17, 25-27, 30], *D. hydei* [32-34], *D. montium* [28, 29], *D. persimilis* [10, 18, 35], *D. prosaltans* [31], *D. pseudoobscura* [24, 30, 39, 42], *D. similans* [30, 38, 41], *D. subobscura* [2, 6-9, 13-16, 21-23, 36, 37], *D. virilis* [3-5, 19, 30], *D. willistoni* [12, 20]. **Gene Symbol** (column A): *l* = lethal; 1 = the number one; *I* = the letter I. **Locus** (column B): (Dp) = duplication; (Df) = deficiency. A number of loci have recently proved to be pseudoallelic (show crossing over with low frequency within subdivisions of an individual locus); such loci are indicated in column C as (pseudo).

	Gene Symbol	Locus	Mutation	Phenotypic Expression
	(A)	(B)	(C)	(D)
			X Chromosome [11, 43]	
1	*l(1)Jl*	0	lethal (1) Jacobs-Muller	Almost completely lethal; survivors scute, sterile
2	*l(1)55a*	0-	lethal (1) 55a	Lethal, heterozygote hyperviable
3	$su\text{-}w^a$	0-	suppressor of apricot	w^a eye color made to resemble w^{co}
4	*y*	0	yellow	Body yellow; bristles and hairs yellow or brown in different alleles
5	*brc*	0	brachymacrochaete	Macrochaetes reduced

continued

5. LINKAGE GROUPS: INVERTEBRATES

Part I. FRUIT FLY

	Gene Symbol	Locus	Mutation	Phenotypic Expression
	(A)	(B)	(C)	(D)
			X Chromosome [11,43]	
6	*ac*	0+	achaete	Postdorsocentrals missing; intraocular and eye hairs fewer
7	*Hw*	0+ (Dp)	Hairy-wing	Extra bristles along wing veins, on head and thorax
8	*sc*	0+	scute	Scutellar bristles missing, others missing or reduced
9	*svr*	0+	silver	Body silvery, bristles dark
10	*su-s*	0+	suppressor of sable	Suppresses *s* and *v*
11	*dor*	0+	deep orange	Eyes orange; female sterile
12	*l(1)7e*	0+	lethal (1) 7e	Dies in larval stage
13	*saw*	0+	sawtooth	Wing hairs serrated
14	*su-b*	0.1	suppressor of black	Suppresses *b*
15	*om*	0.1±	ommatidia	Eyes slightly rough
16	*M(1)Bld*	0.1+ (Df)	Minute (1) Blond	Extreme minute (small bristles, low viability, homozygous lethal)
17	*l(1)7*	0.3	lethal (1) 7	Dies as late larva; tumors present
18	*fla*	0.3±	flat eye	Eyes small, flat
19	*sta*	0.3±	stubarista	Antennae and aristae short, bristles reduced, eye rotated
20	*tw*	0.4±	twisted	Abdomen twisted counterclockwise
21	*mwi*	0.4±	misheld wings	Wings divergent, upheld; eyes oval
22	*uq*	0.5±	unequal wings	Wings short, often unequal
23	*kz*	0.7	kurz	Bristles short, fine; postscutellars often absent
24	*rey*	0.7±	rough eye	Eyes small, rough
25	*pn*	0.8	prune	Eyes brownish, darkening with age, often mottled
26	*mk*	0.8±	murky	Body and eyes dark; female sterile
27	*gt*	0.9	giant	Giant larva, pupa, adult; variable
28	*rsc*	0.9±	reduplicated sex combs	Sex combs on all six legs of male
29	*fc*	0.9±	faulty chaete	Bristles short, thin; some absent
30	*ovi*	0.9±	ovioculus	Eyes small, egg-shaped; male sterile
31	*z*	1.0	zeste	Eyes yellow in female at 25°C; temperature-sensitive; interacts with *w* alleles
32	*fb*	1.0±	fine bristle	Bristles short, fine
33	*l(1)ml*	1.0	lethal (1) melanomalike	Dies as late larva, melanotic inclusions
34	*bsc*	1.1	bent scutellars	Scutellars and other bristles often bent
35	*mis*	1.3±	misproportioned	Abdomen abnormal in shape and size
36	*w*	1.5	white (pseudo)	White eyes, ocelli, testes, malpighian tubes
37	*rst*^{2}	1.7	roughest^2	Eyes rough, body dwarfed, some bristles reduced
38	*To*	2.3-	Tousled	Thoracic bristles disarranged, duplicated
39	*Co*	3.0± (Dp)	Confluens	Wing veins thick, with deltas
40	*nd*	3.0±	notchoid (pseudo with *spl-fa-N*)	Eyes small, wings notched
41	*spl*	3.0±	split (pseudo with *spl-fa-N*)	Eyes rough, small; bristles often split or missing
42	*fa*	3.0±	facet (pseudo with *spl-fa-N*)	Eyes rough, wings nicked
43	*N*	3.0± (often Df)	Notch (pseudo with *spl-fa-N*)	Wings notched; male lethal
44	*Ax*	3.0±	Abruptex	Wings short, veins incomplete; thorax with mid-furrow
45	*rud*	3.3±	ruddle	Eyes reddish brown
46	*slc*	3.6±	slim chaete	Bristles fine, short
47	*Sc*	4.0±	Scotched eye	Ommatidia disarranged; male lethal
48	*dm*	4.6	diminutive	Body and bristles small; female sterile
49	*M(1)3E*	5.0±	Minute (1) 3E	Slight minute (body small, bristles fine, homozygous lethal)
50	*su*^{x}*-dx*	5.0±	suppressor of deltex	*dx* made nearly +; male fertile
51	*ec*	5.5	echinus	Eyes rough, large; facets large
52	*mf*	5.5±	macrofine	Body small, macrochaetes fine
53	*te*	5.6±	tenuchaete	Bristles fine, short; eyes dark
54	*Oc*	5.7±	Ocellarless	One or both ocellar bristles missing
55	*mo*	6.7±	microoculus	Eyes small, wings narrow
56	*amb*	6.8±	amber	Body pale yellow, bristles reduced; male sterile
57	*bi*	6.9	bifid	Wing veins fused into bifid stalk
58	*M(1)4BC*	7.0±	Minute (1) at 4BC	Strong minute (body small, bristles fine, homozygous lethal)
59	*peb*	7.3±	pebbled	Eyes slightly roughened
60	*lac*	7.3±	lacquered	Body color light, glistening; eyes small
61	*rb*	7.5	ruby	Eyes clear ruby, darkening to garnet

continued

5. LINKAGE GROUPS: INVERTEBRATES

Part I. FRUIT FLY

	Gene Symbol	Locus	Mutation	Phenotypic Expression
	(A)	(B)	(C)	(D)
			X Chromosome [11,43]	
62	*dow*	8.0	downy	Bristles fuzzy; male sterile
63	*rg*	11.0	rugose	Eyes rough; wings thin, frayed
64	*bo*	12.5	bordeaux	Eyes dark wine
65	*omm*	12.8	ommatoreductum	Peripheral ommatidia absent, giving rough eye; head, thorax abnormal
66	*cx*	13.6	curlex	Wings bent upward
67	*cv*	13.7	crossveinless	Crossveins absent or nearly so
68	*mur*	14.3	murrey	Eyes reddish purple; body size, bristles reduced
69	*rmp*	14.4±	rumpled	Wings unexpanded, bristles disarranged
70	*rux*	15.0	roughex	Eyes small, rough
71	*Ext*	15.2±	Extras	Wing veins thickened, extra veins present
72	*vs*	16.3	vesiculated	Wings warped, divergent, blistered
73	*dx*	17.0	deltex	Wings thickened and with deltas
74	*ov*	17.5	oval	Eyes oval and rough
75	*tmc*	17.5±	tonomacrochaetes	Macrochaetes thin; abdomen pale
76	shf^2	17.9	shifted^2	Wing veins shifted closer together
77	*cm*	18.9	carmine	Eyes dark ruby
78	*scp*	19.3	scooped	Wings upturned, warped
79	*bis*	19.8± (Df)	bistre	Eyes and ocelli dark brown; male sterile
80	*ct*	20.0	cut	Wings cut to points, scalloped
81	*sn*	21.0	singed (pseudo)	Bristles and hairs curled; female sterile
82	*l(1)mys*	21.7	lethal(1)myospheroid	Dies as embryo with spheroid muscles
83	*ha*	22.7±	hair bristles	Bristles fine, short; fly small
84	*oc*	23.1	ocelliless	Ocelli absent; female sterile
85	*pam*	23.1	platinum	Male body and bristles almost colorless, bristle bases dark; sterile
86	gg^2	23.1±	goggle^2	Eyes bulging, head bristles fewer
87	*ptg*	23.2	pentagon	Thoracic trident and scutellar spot dark
88	*ccw*	23.4±	concave wing	Wings reduced, concave
89	*ch-b*	23.8	chilblained-b	Tarsi conglutinated
90	*tbd*	25.0±	tiny-bristloid	Bristles medium-fine; fly small; viability good
91	*Lg*	27.0±	Large	Body large; late-hatching
92	dd^2	27.2	displaced^2	Antennae sunken; eyes and head deformed
93	*t*	27.5	tan	Body yellowish, antennae light yellow
94	*amx*	27.7-	almondex	Eyes narrow, rough; female sterile
95	*lz*	27.7	lozenge (pseudo)	Eyes narrow, facets abnormal; female usually sterile
96	*tar*	27.7±	tarry	Femur and tibia blackened
97	*dvr*	28.1	divers	Wings short, dark; with *y*, wings curled
98	*sma*	29.9±	smaller	Body size reduced
99	*su-Cbx*	30.0±	suppressor of Contra-bithorax	Almost completely suppresses *Cbx* effect in male
100	*tpw*	30.8±	tapered wing	Wings short, pointed at L3 vein tip
101	*flp*	31.0±	flap wings	Wings concave; eyes bulging, rough
102	*ny*	32.0±	notchy	Wing tips nicked
103	$en\text{-}w^e$	32.0±	enhancer of white-eosin	With w^e alleles, gives nearly white eyes; suppresses *f*
104	*sto*	32.5	stocky	Fly short; eyes large, pear-shaped
105	*clm*	32.6±	clumpy marginals	Marginal wing hairs clumped
106	*ras*	32.8	raspberry	Eyes dark ruby
107	*ww*	32.9±	wider-wing	Wings short, broad
108	*v*	33.0	vermilion (pseudo)	Eyes bright vermilion, ocelli colorless
109	*osh*	33.0±	outshifted	Wings short, divergent; body light tan
110	*dwx*	33.2	dwarfex	Body small, wings coarse
111	*sbr*	33.4	small bristle	Bristles small, some missing
112	*csk*	33.4±	costakink	Wings reduced, costal vein kinked
113	*bla*	33.6±	bladder-wing	Wings deformed, with bladders; male sterile
114	*m*	36.1+	miniature	Wings small, dark
115	*dy*	36.2-	dusky	Wings small, dark
116	*ty-l*	36.4	tiny-like	Bristles short, fine
117	*trb*	37.0±	thread bristle	Bristles short, fine
118	*fw*	38.3	furrowed	Eyes furrowed, scutellum short, bristles gnarled
119	*alo*	38.3±	alopecia	Microchaetes nearly absent
120	*ups*	40.8	upright scutellars	Posterior scutellars vertical
121	*som*	40.8	sombre	Body dark, eyes dull

continued

5. LINKAGE GROUPS: INVERTEBRATES

Part I. FRUIT FLY

	Gene Symbol (A)	Locus (B)	Mutation (C)	Phenotypic Expression (D)
			X Chromosome [11, 43]	
122	*up*	41.0±	upheld	Wings held upright
123	*pun*	41.1±	puny	Fly small, late-hatching
124	*taw*	41.1±	tawny	Head and thorax dark, abdomen light
125	*wy*	41.9	wavy	Wings waved, curled upward
126	*kk*	42.0±	kinky	Bristles bent or forked
127	*s*	43.0	sable	Body dark
128	*cop*	43.3±	copper	Eyes brownish red
129	*ten*	43.9	tenuischaete	Bristles short, thin; body small
130	*g*	44.4	garnet (pseudo)	Eyes garnet pink
131	*ty*	44.5	tiny	Bristles, body small; female sterile
132	*na*	45.2	narrow abdomen	Abdomen cylindrical; female sterile
133	*shp*	47.5±	shrimp	Overall size reduction
134	*thb*	47.6±	thin bristle	Bristles thin
135	*pl*	47.9	pleated	Wings pleated longitudinally
136	*rim*	48.1±	rimy	Eyes brownish with white hairs; wings pleated
137	*sge*	48.4±	shifted genitals	Genitalia rotated
138	*thm*	48.9	thin-macros	Macrochaetes thin
139	*vb*	49.3	vibrissae	Vibrissae in tuft
140	*mgt*	49.6±	midget	Body small; late-hatching
141	*thv*	49.7±	thick vein	Wing veins thick; eyes small, dark
142	*sla*	50.0±	slimma	Body narrow
143	*sd*	51.5	scalloped	Wing margins excised
144	*exi*	51.5±	exiguous	Body small, dark
145	*tc*	51.6±	tinychaete	Bristles fine
146	*Bg*	51.6	Bag	Wings short, blunt, inflated
147	*smt*	51.9±	small thorax	Head and thorax small
148	*drw*	52.3±	droopy wing	Fly small, wings drooped; male sterile
149	*ber*	52.2±	berrytail	Abdomen narrow, with berrylike posterior protrusion bearing abnormal genitalia
150	*msc*	52.6±	melanoscutellum	Scutellum dark; eyes and wings abnormal in shape
151	*Shw*	53.3	Shaker-downheld	Legs, abdomen shake under ether; wings droop
152	*sl*	53.5	small-wing	Wings short, oblong; eyes large
153	*mc*	54.0	microchaete	Hairs irregular, bristles small
154	*un*	54.4	uneven	Eyes rough, small
155	*r9*	54.5	rudimentary9	Wings truncated; female sterile
156	*acc*	54.5+	acclinal wing	Wings upheld, sloping
157	*if3*	55.0±	inflated3	Wings inflated, veins thickened
158	*M(1)o*	56.6	Minute (1) o	Minute (bristles fine, viability low, homozygous lethal)
159	*f*	56.7	forked (pseudo)	Bristles short, gnarled
160	*B*	57.0 (Dp)	Bar	Eyes narrow bar in homozygote, kidney-shaped in heterozygote
161	*der*	57.2±	deranged	Thoracic bristles disarranged; wings upheld
162	*Sh*	58.0	Shaker	Legs, abdomen shake under light ether
163	*siw*	58.5±	side wing	Wings held parallel to sides of abdomen
164	*od*	59.2	outstretched	Wings divergent
165	*sy*	59.2	small-eye	Eyes small, rounded
166	*Bx*	59.4	Beadex	Wings excised
167	*rwg*	59.5±	reduced wings	Wings short, upheld; wing hairs disarranged
168	*fu*	59.5	fused	Wing veins fused; ocelli, ocellar bristles reduced or absent
169	*hdp*	59.6±	heldup	Wings upheld
170	*bk*	59.8±	buckled	Wings misshapen, divergent
171	*crk*	60.1±	crooked setae	Bristles disarranged, abnormal
172	*smd*	60.1±	smalloid	Body size reduced
173	*ton*	60.1±	tonochaete	Bristles short, fine
174	*meg*	61.9±	megaoculus	Eyes rough; eyes, wings abnormally shaped
175	*M(1)36f*	62.0±	Minute (1) 36f	Slight minute (bristles fine, homozygous lethal)
176	*car*	62.5	carnation	Eyes dark ruby
177	*M(1)n*	62.7	Minute (1) n	Minute type (fine bristles, low viability, homozygous lethal)
178	*fo*	63.0±	folded	Wings unexpanded
179	*kno*	63.9±	knobbyhead	Head small, abnormal; male infertile
180	*sw*	64.0	short-wing	Wings trimmed, warped; eyes reduced, rough
181	*su-f*	64.0±	suppressor of forked	Certain *f* alleles made nearly +

continued

5. LINKAGE GROUPS: INVERTEBRATES

Part I. FRUIT FLY

	Gene Symbol	Locus	Mutation	Phenotypic Expression
	(A)	(B)	(C)	(D)
	X Chromosome [11,43]			
182	*mel*	64.1±	melanized	Body slightly dark, eyes dull red
183	*wa-l*	64.4±	warty-like	Ommatidia disarranged
184	*ot*	65.1±	outheld	Wings held out; male inviable, sterile
185	bb^5 (called *bb*)	66.0	bobbed	Bristles small, sclerites irregular
	Chromosome II [1]			
186	*net*	0-	net	Extreme plexus venation
187	*al*	0	aristaless	Aristae reduced, scutellars divergent
188	*l(2)gl*	0±	lethal (2) giant larva	Larval lethal
189	*ocr*	0	ochracea	Eye color light, darkening with age
190	*ex*	0.1	expanded	Wings broad, spread; eyes rough
191	*ds*	0.3	dachsous	Wings shorter, crossveins closer
192	*S*	1.3	Star (pseudo)	Eyes small, rough; homozygous lethal
193	*Su-S*	1.3±	Suppressor of Star	Suppresses *S*; *Su-S/S* is +
194	*ast*	1.3±	asteroid	Eyes small, rough
195	*shr*	2.3±	shrunken	Body small, wizened
196	*shv*	3.8±	short vein	Constant terminal gaps in veins L2 and L4
197	*ho*	4.0	heldout	Wings extended
198	*fes*	5.0±	female-sterile	Eggs do not develop
199	*E-S*	6.0±	Enhancer of Star	Increases expression of *S*
200	*Cy*	7.0	Curly	Wings curled upward; homozygous lethal
201	*l(2)ay*	8.3	lethal (2) ay	Lethal
202	*Dt*	10.0±	Detached	Vein L2 does not reach margin
203	*ang*	10.5	angle wing	Wings held up from dorsal surface
204	*ed*	11.0	echinoid	Eyes large, rough
205	*M(2)C*	11.0-12.0 (Df)	Minute (2) Curry	Fairly strong minute
206	*ft*	12.0	fat	Body short, fat; scutellar bristles far apart
207	*G*	12.0	Gull	Wings large, spread; homozygous lethal
208	*M(2)z*	12.9±	Minute (2) z	Medium minute
209	*M(2)B*	13.0 (Df)	Minute (2) Bridges	Medium minute
210	*dp*	13.0	dumpy	Wings truncated; vortices on thorax
211	*dw-24F*	13.0±	dwarf in 24F	Eyes dull, body dwarfed
212	*M(2)S1*	15.0	Minute (2) Schultz' 1	Strong minute
213	*l(2)cg*	15.0±	lethal (2) comb-gap	Lethal from *cg* stock
214	*Sk*	16.0	Streak	Central streak on thorax; homozygous lethal
215	*tkv*	16.0±	thick-veins	Veins thick, irregular
216	*cl*	16.5	clot	Eye color maroon, close to sepia (*se*); male sterile
217	*pi*	17.0±	pied	Facets jumbled
218	*Sp*	22.0	Sternopleural	Extra sternopleural bristles; homozygous lethal
219	*spd*	22.3±	spade	Wings shortened, broad
220	*gt-4*	24.0	giant-4	Giant fly
221	*d*	31.0	dachs	Tarsi 4-jointed, venation shifted
222	*fy*	33.0±	fuzzy	Thoracic hairs fuzzy
223	*fol*	39.0±	folded wings	Wings folded; overlap
224	*da*	39.3±	daughterless	Homozygous female produces no daughters
225	*J*	41.0	Jammed	Wing narrow strip
226	*M(2)S11*	43.0±	Minute (2) Schultz' 11	Slight minute
227	*ab*	44.0	abrupt	Shortened L5 vein, scutellars few
228	*oph*	45.0±	ophthalmopedia	Eyes kidney-shaped or with appendage
229	*rk*	46.0±	rickets	Segments of legs flattened and bent
230	$l(2)bs^3$*-d*	46.0±	lethal (2) with bs^3-d	Lethal
231	*M(2)e*	46.0±	Minute (2) e	Medium minute
232	*b*	48.5	black	Body, legs, veins black
233	*j*	48.7	jaunty	Wings upturned
234	*el*	50.0	elbow	Wings bent, alulae and balancers small
235	*lm*	50.0±	limited	Sternites small; female sterile
236	*M(2)S13*	50.0±	Minute (2) Schultz' 13	Strong minute
237	*l(2)H*	50.0±	lethal (2) Humphrey	Pupal semilethal
238	*Su-H*	50.5	Suppressor of Hairless	Homozygous lethal
239	*rd*	51.0	reduced	Bristles small, irregular; female sterile
240	*pu*	51.0±	pupal	Wings unexpanded

continued

5. LINKAGE GROUPS: INVERTEBRATES

Part I. FRUIT FLY

	Gene Symbol	Locus	Mutation	Phenotypic Expression
	(A)	(B)	(C)	(D)
	Chromosome II [1]			
241	*pys*	52.0±	polychaetous	Extra and double bristles
242	*cr-u*	52.5±	cream-underscored	Specific dilutor of w^e and Pale; male sterile
243	*nub*	53.0	nubbin	Wings very small and thin with tendency to curve up or down
244	*ck*	53.0±	crinkled	Wings flimsy
245	*rdo*	53.0±	reduced ocelli	Ocelli reduced in size, color moved to region between ocelli
246	*l(2)Bld*	53.1	lethal (2) opposite T(1,2) Bld	Lethal
247	*M(2)S5*	53.5	Minute (2) Schultz' 5	Medium minute
248	*hk*	53.9	hook	Bristles bent or barbed
249	*bri*	54.3±	bright	Eye color bright red
250	*pr*	54.5	purple	Eye color purplish ruby
251	*rn*	54.5±	rotund	Wings round, tarsi 3-jointed; sterile
252	*rh*	54.7±	roughish	Eyes moderately rough
253	*Bl*	54.8	Bristle	Bristles short, beaded; homozygous semilethal
254	*Alu*	54.9	Alula	Alula fused to wing; wing warped
255	*Jag*	54.9	Jagged	Wings nicked, eyes rough
256	*lt*	55.0-	light	Eye color yellowish pink
257	*tri*	55.0±	trident	Thorax darkened
258	*M(2)D*	55.0± (Df)	Minute (2) D	Body color and bristles pale
259	*rl*	55.1-	rolled	Wing edges rolled, frayed
260	*M(2)S2*	55.1 (Df)	Minute (2) Schultz' 2	Minute type
261	*M(2)S4*	55.1 (Df)	Minute (2) Schultz' 4	Medium minute
262	*M(2)S8*	55.1 (Df)	Minute (2) Schultz' 8	Slight minute
263	*M(2)S10*	55.1 (Df)	Minute (2) Schultz' 10	Slight minute
264	*stw*	55.1	straw	Body, wings, bristles yellow
265	*blt*	55.2±	blot	Wings inflated, blackened
266	*Cu*	55.2±	Curl	Lateral compression and indentation-fold of unfolded imaginal wing
267	*tk*	55.3	thick	Legs, tarsi thickened; wings short
268	*pk*	55.3	prickle	Bristles, hairs irregular
269	*ap*	55.4	apterous	Wings, balancers missing
270	*msf*	55.6-	misformed	Eyes misformed, wings crumpled
271	*bur*	55.7±	burgundy	Dull, darkish-brown eye color
272	*ti*	55.9	tarsi irregular	Tarsal segments fused, eyes rough
273	*ltd*	56.0±	lightoid	Eye color translucent yellowish pink, ocelli colorless
274	*M(2)S12*	56.0±	Minute (2) Schultz' 12	Slight minute
275	*std*	56.5±	staroid	Eyes small, very rough; male sterile
276	*ta*	56.6±	tapered	Wings narrow and pointed, veins close
277	*dil*	57.0±	specific dilutor	Dilutor of *bw* and *w* alleles
278	*buo*	57.1	burnt orange	Eye color orange brown
279	*M(2)38b*	57.0±	Minute (2) 38b	Extreme minute
280	*cn*	57.5	cinnabar	Eye color bright scarlet, ocelli colorless
281	*puf*	58.0±	puff	Wings blistered
282	*blo*	58.5	bloated	Wings ballooned, extra veins
283	*smk*	58.6±	smoky	Body color dark
284	*Np*	58.7-60.2 (Df)	Notopleural	Bristles short, wings broad; homozygous lethal
285	*at*	60.1±	arctus oculus	Number of facets reduced
286	*arch*	60.5±	arch	Wings downcurved in both axes
287	*ad*	60.7	arcoid	Wings arched, broad, short; crossveins close
288	*chl*	60.8	chaetelle	Bristles very small, slight plexus
289	*whd*	61.0±	withered	Wings warped or shrunken
290	*tom*	61.5±	tomboy	Homozygous female with male-like pigmentation of posterior tergites
291	*en*	62.0	engrailed	Scutellar notch, broken veins, extra sex comb
292	*upw*	62.0±	upward	Wings upturned
293	*l(2)rn*	63.0±	lethal (2) with rotund	Lethal
294	*Bkd*	65.0±	Blackoid	Dark body color
295	*M(2)40c*	65.0±	Minute (2) 40c	Minute type
296	*po*	65.2	pale-ocelli	Ocelli nearly colorless
297	*sca*	66.7	scabrous	Eyes rough, some bristles missing
298	*vg*	67.0	vestigial	Wings, balancers vestigial
299	*l(2)C*	67.0	lethal (2) Curry	Lethal before pupal stage

continued

5. LINKAGE GROUPS: INVERTEBRATES

Part I. FRUIT FLY

	Gene Symbol	Locus	Mutation	Phenotypic Expression
	(A)	(B)	(C)	(D)
	Chromosome II [1]			
300	*wx*	69.7	waxy	Wings heavy, waxy; male sterile
301	Up^{H20}	70.0±	Upturned H20	Wings curled
302	$l(2)mr^2$	70.0±	lethal (2) with morula^2	Lethal
303	*Pfd*	70.8	Pufdi	Wings puffed, divergent; homozygous lethal
304	*bat*	71.0	bat	Wings extended, bent back
305	*cg*	71.1	comb-gap	Sex combs large; gap in wing vein L4; female sterile
306	*dr*	71.2±	droopy	Wings spread wide apart and drooping
307	*sf*	71.5±	safranin	Eye color dark chocolate
308	*L*	72.0	Lobe	Eyes small, nicked at anterior edge
309	*kn*	72.3	knot	Veins L3 and L4 close; eyes oblique
310	*ch*	72.5	chubby	Larva, pupa, adult short
311	*dke*	73.0±	dark eye	Eye color soft, dark, dull, with tiny fleck
312	*gp*	74.0±	gap	Vein L4 broken
313	*c*	75.5	curved	Wings thin, spread, lifted, curved
314	*Wr*	76.0±	Wrinkled	Wings wrinkled; suppresses *L*
315	*M(2)S7*	77.5	Minute (2) Schultz' 7	Strong minute
316	*pw-c*	79.0±	pink-wing-c	Eye color dilute, wings short, blunt
317	*fr*	80.0±	fringed	Wing margins ragged
318	*fj*	81.0±	four-jointed	Tarsi 4-jointed; wings short
319	*rf*	81.0±	roof wings	Wings drooped at sides
320	*wt*	82.0±	welt	Eyes seamed, reduced
321	*abr*	83.0±	abero	Abdominal bands irregular; wings frayed, eyes rough; female sterile
322	*nw*	83.0±	narrow	Wings narrow
323	*I-f*	86.5	Intensifier of forked	Enhances *f*
324	*sm*	91.5	smooth	Abdomen hairless; sterile
325	*M(2)173*	92.3	Minute (2) 173	Moderate minute
326	*hy*	93.3	humpy	Thorax ridged, wings truncated
327	*l(2)Su-H*	99.0±	lethal (2) from Suppressor of Hairless	Lethal
328	*a*	99.2	arc	Wings broad, bent down, crossveins closer
329	*M(2)l*	99.0-102.2 (Df)	Minute (2) 1	Extreme minute
330	*px*	100.5	plexus	Network of extra veins
331	*pa*	101.0±	patulous	Wings spread wide apart
332	$M(2)l^2$	101.2	Minute (2) 1^2	Slight minute
333	*hv*	104.0	heavy vein	Veins thick, posterior crossveins oblique
334	*l(2)bw*	104.0±	lethal (2) brown	Probable deficiency; lethal
335	*bw*	104.5	brown	Eye color brownish to garnet
336	*mi*	104.7	minus	Bristles hairlike; body small; female sterile
337	*abb*	105.5	abbreviated	Bristles slightly reduced
338	*slt*	106.3	slight	Body small, bristles reduced; female sterile
339	*pd*	106.4	purpleoid	Eye color dark pink, like purple *(pr)*
340	*ll*	106.7	lanceolate	Wings narrow, pointed
341	*mr*	106.7±	morula	Eyes rough, bristles small; female sterile
342	*l(2)ax*	106.9	lethal (2) ax	Very early larval lethal
343	*sp*	107.0	speck	Black speck in wing axil; body color olive
344	*or*	107.2	orange	Bright orange eye color
345	*Px*	107.0-107.4 (Df)	Plexate	Venation as in blistered mutation *(bs)*; veins thickened, broken; homozygous lethal
346	*bs*	107.3	blistered	Wings blistered, small; extra veins
347	*Pin*	107.3±	Pin	Thoracic bristles pinlike
348	*ba*	107.4	balloon	Wings inflated, extra veins
349	*M(2)33a*	108.0± (Df)	Minute (2) 33a	Strong minute
	Chromosome III [1]			
350	*ru*	0	roughoid	Eyes small, rough; erupted facets
351	*mp*	0	microptera	Wings small, ballooned; tarsi 4-jointed
352	*aa*	0±	anarista	Aristae small, without branches
353	*ve*	0.2	veinlet	Longitudinal wing veins interrupted
354	*R*	1.4	Roughened	Eyes rough; homozygous semilethal
355	*rai*	17.0±	raisin	Deep brown eye color
356	*jv*	19.2	javelin	Bristles and hairs cylindrical
357	*dv*	20.0	divergent	Wings spread

continued

5. LINKAGE GROUPS: INVERTEBRATES

Part I. FRUIT FLY

	Gene Symbol	Locus	Mutation	Phenotypic Expression
	(A)	(B)	(C)	(D)
	Chromosome III [1]			
358	*Me*	20.0±	Moire	Eye color brownish, 7 flecks; homozygous lethal
359	*Hn*	23.0	Henna	Eye color dull, dark; homozygous lethal
360	*be-3*	25.0±	benign tumor in 3	Nonlethal melanotic tumors
361	*se*	26.0	sepia	Eye color brownish red, darkening to black
362	*su-t*	26.0±	suppressor of tan	Converts *t* to +
363	*h*	26.5	hairy	Extra hairs on scutellars, veins, pleurae, and head
364	*abd*	27.0±	abdominal	Abdominal bands broken, etched
365	*rs*	35.0	rose	Eye color translucent pink
366	*eyg*	35.5	eye-gone	Eyes and head reduced
367	*gv*	36.2	grooved	Longitudinal medial groove in thorax
368	*cr-3*	36.5±	cream in 3	Specific dilutor of w^e eye color
369	*rt*	37.0±	rotated	Abdomen twisted counterclockwise
370	*app*	37.5	approximated	Crossveins close; tarsi 4-jointed
371	*pyd*	39.0±	polychaetoid	Extra bristles
372	*M(3)S37*	39.7±	Minute (3) Schultz' 37	Extreme minute
373	*tt*	40.0	tilt	Wings spread, warped, with gap in vein L3
374	*M(3)33j*	40.2 (Df)	Minute (3) 33j	Medium minute
375	*M(3)h*	40.2	Minute (3) h	Medium minute; allele of *M(3)33j*
376	*M(3)y*	40.2	Minute (3) y	Medium minute; allele of *M(3)33j*
377	*vo-3*	40.4±	vortex in 3	Intensifier of dp^v
378	*D*	40.4+	Dichaete	Wings spread; homozygous lethal
379	*Ly*	40.5 (Df)	Lyra	Wings cut, narrow; homozygous lethal
380	*Gl*	41.4	Glued	Eyes small, facets rounded; homozygous lethal
381	*fz*	41.7±	frizzled	Thoracic hairs, bristles turn toward midline
382	*rp*	41.7±	rotated-penis	Male genitalia rotated; male sterile
383	*wk*	42.0±	weak	Bristles weak, irregular; body small
384	*Wi*	43.0	Washed eye	Modified *w*; homozygous lethal
385	*th*	43.2	thread	Aristae threadlike, without branches
386	*mb*	43.4±	minusbar	Modified *B* to larger eye
387	*Cm*	43.5±	Crimp	Posterior wing edge crimped; homozygous lethal
388	*bul*	43.6	bulge	Eyes bulging, wings squared off
389	*M(3)S38*	44.0±	Minute (3) Schultz' 38	Strong minute
390	*st*	44.0	scarlet	Eye color scarlet, ocelli white
391	*tra*	45.0±	transformed	Transforms female to normal-appearing male
392	*cp*	45.3	clipped	Wing margins clipped
393	*mot-28*	46.0	mottled-28	Eyes mottled with brown
394	*W*	46.0	Wrinkled	Wings incompletely unfolded, pebbled
395	*as*	46.0±	ascute	Wings held downward
396	*je*	46.0±	jelly	Eye color dark pinkish
397	*Pdr*	46.0±	Purpleoider	Intensifier of *pd*
398	*in*	46.9	inturned	Thoracic bristles directed toward midline
399	*M(3)S39*	47.0±	Minute (3) Schultz' 39	Strong minute
400	*dn*	47.0±	doughnut	Eye of *se dn* with light central spot; male sterile
401	*ri*	47.1	radius incompletus	Vein L2 shows gap
402	*eg*	47.3	eagle	Wings spread, raised
403	*Dfd*	47.5	Deformed	Eyes small; homozygous lethal
404	*wp*	47.5	warped	Wings spread, doubly warped
405	*pb*	47.7	proboscipedia	Mouth parts footlike; adult lethal; female sterile
406	*p*	48.0	pink	Eye color dull ruby
407	*Bb*	48.0±	Bubble	Wings small, inflated; male sterile; homozygous female lethal
408	*bod*	48.3	bowed	Wings arched
409	*tet*	48.5	tetraltera	Wings haltere-like
410	*by*	48.7	blistery	Wings blistered distally
411	*M(3)S34*	49.0±	Minute (3) Schultz' 34	Slight minute
412	*ma*	49.7	maroon	Eye color dull ruby
413	*cu*	50.0	curled	Wings upcurved, body dark, postscutellars crossed
414	*M(3)S31*	50.0 (Df)	Minute (3) Schultz' 31	Medium minute
415	*mu*	50.0±	mussed	Wings thin, crumpled
416	*ry*	51.0±	rosy	Eye color deep ruby
417	*kar*	52.0	karmoisin	Eye color like scarlet mutation *(st)* but duller, ocelli colorless

continued

5. LINKAGE GROUPS: INVERTEBRATES

Part I. FRUIT FLY

	Gene Symbol (A)	Locus (B)	Mutation (C)	Phenotypic Expression (D)
	Chromosome III [1]			
418	*c3G*	55.0±	crossover suppressor in 3 of Gowen	Eliminates crossing over
419	*red*	55.5±	red	Red malpighian tubules
420	*jvl*	56.7	javelin-like	Bristles cylindrical, crooked
421	*cv-c*	57.9	crossveinless-c	Posterior crossvein absent or reduced
422	*Sb*	58.2	Stubble	Bristles short, thick; homozygous lethal
423	*ss*	58.5	spineless	Bristles very small
424	*bx*	58.8	bithorax (pseudo)	Balancers winglike; metathorax resembles mesothoras
425	*Rf*	59.0±	Roof	Wings drooping at sides
426	*cal*	59.5±	coal	Black body color, similar to e^4
427	*fl*	59.9	fluted	Wings creased, darkish
428	*sr*	62.0	stripe	Dark dorsal stripe
429	*M(3)f*	62.4	Minute (3) f	Minute type
430	*gl*	63.1	glass	Eye color dilute, facets fused
431	*gl-l*	64.0±	glass-like	Eyes orange, rough, and small
432	*k*	64.0±	kidney	Eyes kidney-shaped
433	*M(3)S35*	64.0±	Minute (3) Schultz' 35	Extreme minute
434	*sed*	64.5±	sepiaoid	Eye color chocolate
435	*cv-d*	65.0±	crossveinless-d	Posterior crossvein absent or reduced
436	*Cur*	66.0±	Curl	Curly wings; homozygous lethal
437	*Dl*	66.2	Delta	Veins thick at margin; homozygous lethal
438	*H*	69.5	Hairless	Some bristles and hair missing; homozygous lethal
439	*e*	70.7	ebony	Body color black
440	*det*	72.5	detached	Crossveins broken, wings folded under
441	*cd*	75.7	cardinal	Eye color dull scarlet, ocelli white
442	*wo*	76.2	white ocelli	Ocelli colorless
443	*obt*	77.5±	obtuse	Wings short, blunt
444	*bar-3*	79.1	bar-3	Phenotype like *B/B*
445	*M(3)124*	79.7	Minute (3) 124	Strong minute; allele of *M(3)w*
446	*M(3)B*	79.7	Minute (3) Burkart	Moderate minute; allele of *M(3)w*
447	*M(3)B*^{2}	79.7	Minute (3) Bridges	Strong minute; allele of *M(3)w*
448	*M(3)w*	79.7	Minute (3) w	Strong minute
449	*l(3)a*	79.7	lethal (3) first found	Lethal; allele of *M(3)w*
450	*M(3)Fla*	80.0±	Minute (3) Florida	Strong minute; allele of *M(3)w*
451	*M(3)36e*	84.5	Minute (3) 36e	Medium minute
452	*M(3)be*	87.0±	Minute (3) beta	Medium minute
453	*mah*	88.0±	mahogany	Eye color brownish, darkening
454	*Pr*	90.0	Prickly	Bristles vestigial; homozygous semilethal
455	*M(3)j*	90.2	Minute (3) j	Extreme minute
456	*l(3)PR*	90.2	lethal with In(3R)P	Lethal; allele of *M(3)j*
457	*tx*	91.0±	taxi	Wings divergent
458	*ro*	91.1	rough	Eyes rough, small
459	*l(3)XaR*	91.8	lethal (3) XaR	Balancer of *T(2,3) Xa*
460	*cmp*	93.0±	crumpled	Wings smaller, crumpled
461	*Bd*	93.8	Beaded	Wing margins excised; homozygous lethal
462	*Pw*	94.1	Pointed-wing	Wings pointed at tip; homozygous lethal
463	*bf*	95.0±	brief	Body small, bristles minute-like; male sterile
464	*rsd*	95.4	raised	Wings rise straight up
465	*su*^{B}*-pr*	95.5	suppressor of purple	Suppresses purple *(pr)*
466	*ra*	97.3	rase	Bristles, hairs smaller, fewer
467	*Dp*	99.3±	Duplication	Similar to ultra bar
468	*ld*	100.0±	loboid	Eyes lobe-like
469	*ca*	100.7	claret	Eye color clear ruby
470	*M(3)l*	101.0	Minute (3) l	Medium minute
471	*bv*	104.3	brevis	Bristles short, stubby
472	*M(3)g*	106.2	Minute (3) g	Slight minute, requires *E-M(3)g*
	Chromosome IV [40]			
473	*ci*	0	cubitus-interruptus	Vein L4 interrupted
474	*M-4*	0-0.2±	Minute-4	Medium minute; deficiency for *ci*, *ar*, *gvl*, and *Scn*
475	*ar*	0-0.2	abdomen rotatum	Abdomen twisted clockwise
476	*gvl*	0.2	grooveless	Scutellar groove diminished

continued

5. LINKAGE GROUPS: INVERTEBRATES

Part I. FRUIT FLY

	Gene Symbol (A)	Locus (B)	Mutation (C)	Phenotypic Expression (D)
				Chromosome IV [40]
477	*bt*	1.4	bent	Wings bent, legs knobby
478	*ey*	2.0	eyeless	Eyes small or absent
479	*sv*	3.0	shaven	Abdominal bristles fewer

Contributors: (a) Warren, Katherine Brehme, (b) Novitski, E.

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Part II. PARASITIC WASP

Habrobracon juglandis has 10 pair of chromosomes; linkage groups have been found for 8 pair. **Linkage** (column B): slant line (/) indicates complete linkage.

	Gene Symbol (A)	Linkage (B)	Recombination Percentage (C)	Mutation (D)	Phenotypic Expression (E)
					Linkage Group I
1	*Sk*	*Sk--r*	12	Speckled	Bright red flecks of pigment in white eye
2	*r*	*r--gl*	13	reduced	Small wings; reduced, irregular venation
3	*gl*	*gl--x*	30	glass	Small eyes, lacking facet outlines
4	*X*	*X--fu*	10	Sex	9 alleles known (each consisting of many factors determining sex differences) that produce similar phenotypes in males and in females
5	*fu*	*fu--sb*	22	fused	Antennal segments fused; tarsal segments lacking or fused

continued

5. LINKAGE GROUPS: INVERTEBRATES

Part II. PARASITIC WASP

	Gene Symbol	Linkage	Recombination Percentage	Mutation	Phenotypic Expression
	(A)	(B)	(C)	(D)	(E)
					Linkage Group I
6	*sb*	*sb--bl*	42	stubby	Males with antennae 7-9 segments long; females with antennae 5-7 segments long
7	*bl*	*bl--le*	30	black	Body color black
8	*le*	*le--c*	12	lemon	Body color pale lemon yellow
9	*c*	*c--l*	14	canteloupe	Eyes light pink, darken to deep red
10	*l*	*l--n*	3	long	Antennal segments elongated; leg segments longer and thinner than in wild type
11	*n*	*n--ho*	7	narrow	Narrow wings; cuts off irregular slices of costal and inner wing margins
12	*ho*	*ho--vl*	8	honey	Body lacks black pigment entirely
13	*vl*	*vl--ro*	15	veinless	Wing veins missing, except along costal margin
14	*ro*	*ro--bu*	12	rough	4th radius vein absent, adjacent veins roughened
15	*bu*	*bu--cr*	37	bulged	Eyes abnormally bulged transversely
16	*cr*	*cr--sl/co*	41	crescent	Eyes small; ocelli crescent-shaped, pigment reduced
17	*sl*	*sl/co--ct*	33	semilong	Antennal and leg segments lengthened
18	*co*			coalescent	Antennal segments coalescent
19	*ct*	*ct--rd*	32	cut	Outer wing margin indented or straightened, giving cut appearance
20	*rd*	*rd--gy*	37	red	Eye color varies from light red to dark red, almost black with temperature increase
21	*gy*	*gy--ac/el*	7	gynoid	Short antennae in male, resembling those in female; abdominal sclerites resemble those in female
22	*ac*	*ac/el--gy*	7	aciform	Terminal half of antennae very slender, needlelike
23	*el*			eyeless	Head malformed; eye rudiments present
					Linkage Group II
24	*k*	*k--dw*	28	kidney	Eyes kidney-shaped
25	*dw*	*dw--m*	5	dwindling	Irregularity and fusion of antennal segments
26	*m*	*m--o*	11	miniature	Reduced body size; semilethal: many die as pupae
27	*o*	*o--m*	11	orange	Eyes orange, varying to pink and red
					Linkage Group III
28	*bk*	*bk--wh/pl*	25	broken	Outer margin of primary wing broken and wings fragile
29	*wh*	*wh/pl--st*	9	white	White eye; ocelli colorless
30	*pl*			pellucid	Compound eyes semitransparent
31	*st*	*st--wh/pl*	9	stumpy	Extreme reduction of tarsal segments
					Linkage Group IV
32	*sv*	*sv--td*	23	shot-veins	Wing veins broken and distorted
33	*td*	*td--ma*	27	truncated	Wings extremely reduced, irregular in shape
34	*ma*	*ma--td*	27	maroon	Light ocelli; compound eyes deep reddish brown
					Linkage Group V
35	*wa*	*wa--br*	22	wavy	Wings shortened, costal margin wavy
36	*br*	*br--wa*	22	broad	Thorax abnormally broadened
					Linkage Group VI
37	*ta*	ta--un^2	40	tapering	Antennae deficient, with much fusion and irregularity of segments distally
38	un^2	un^2--ta	40	undulating-2	Surface of wings in undulating waves
					Linkage Group VII
39	*pk*	pk/ew^3		pink	Compound eyes pink
40	ew^3			extended wings	Wings extended in active wasps
					Linkage Group VIII
41	*wt*	*wt--bf*	17	wet	Wing microchaetae very long and irregular, giving wet appearance
42	*bf*	*bf--wt*	17	black feet	Tarsi abnormally black

Contributors: (a) Whiting, P. W., (b) Novitski, E.

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continued

5. LINKAGE GROUPS: INVERTEBRATES

Part II. PARASITIC WASP

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Part III. SILKWORM

Bombyx mori has 28 pair of chromosomes; linkage groups have been found for 15 pair. **Gene Symbol** (column A): *l* = lethal.

	Gene Symbol	Locus	Mutation	Phenotypic Expression
	(A)	(B)	(C)	(D)
				Linkage Group I (Z Chromosome)
1	*os*	0	sex-linked	Low translucency of larva
2	*Ge*	14.0	Giant egg	Length and width 1.26 and 1.11, respectively, times the normal egg
3	*e*	36.4	elongate	First and second abdominal segments of larva unusually elongated
4	*Vg*	38.7	Vestigial	Wings poorly developed
5	*od*	49.6	translucent	Skin of larva shows high translucency
				Linkage Group II
6	*P*	0	Plain	Full grown larva white; $+^{p}$, p^{B}, p^{M}, p^{S}, p^{Sa}, multiple or pseudoalleles of *p*
7	*S*	6.1	New striped	Dark stripe on larva; heterozygote almost as dark as homozygote
8	*Gr*	6.9	Gray egg	Milky white shell, dark serosa pigment
9	*Y*	25.6	Yellow blood	Deep yellow hemolymph in larva
10	*oa*	26.7	mottled translucent	Mottled translucency on larval skin
11	*Rc*	31.8	Rusty	Yellowish-brown cocoon, lighter inner layer
				Linkage Group III
12	*Ze*	0	Zebra	Black band on anterior end of each segment; pair of black spots on ventral side of each larval segment
13	*ap*	0	apodal	All thoracic legs rudimentary
14	*lem*	22.8	lemon	Greenish-yellow coloring over skin visible from 2nd instar
				Linkage Group IV
15	*L*	0	Multilunar	Pairs of large brownish or yellowish round spots on thoracic and abdominal segments
16	*sk*	25.8	stick	Larva body slender and hard
17	*Spc*	33.1	Speckle	Many dark spots on larval skin; female sterile
				Linkage Group V
18	*pe*	0	pink-eyed	White egg; pigment absent from serosa
19	*ok*	4.7	kinshiryu	High translucency of larva
20	*re*	31.7	red egg	Reddish-brown serosa
21	*oc*	40.8	chinese	High translucency of larva
				Linkage Group VI
22	*E*	0	Plain supernumerary legs	Supernumerary legs in 1st and 2nd abdominal segments of larva; E^{Ca}, E^{D}, E^{H}, E^{Kp}, E^{N}, multiple or pseudoalleles of *E*
23	*Nc*	1.4	No crescent supernumerary legs	Crescents absent; supernumerary leg in the 2nd abdominal segment
24	$+^{M}$	3.0	Tetra molting	Standard type, larva pupates after 4th molt; M^{3}, M^{5}, multiple or pseudoalleles of $+^{M}$
25	*b2*	8.0	brown egg-2	Grayish-brown pigment in serosa
26	*F*	13.6	Flesh	Cocoon color reddish-yellow or salmon color
27	*l-k*	17.7	lethal-k	Embryo killed few days before hatching

continued

5. LINKAGE GROUPS: INVERTEBRATES

Part III. SILKWORM

	Gene Symbol	Locus	Mutation	Phenotypic Expression
	(A)	(B)	(C)	(D)
				Linkage Group VII
28	*q*	0	quail	Larval body tinted reddish-purple and covered with shredlike lines
29	*Gb*	0.7	Green b	Greenish cocoon color
30	*obt*	21.0	b_8-mottled	Moderate translucency of larva; not lethal
				Linkage Group VIII
31	*ae*	0	amylase negative	Amylase in digestive fluid weak
32	*be*	1.1	amylase negative	Amylase in body fluid (hemolymph) weak
				Linkage Group IX
33	*I*	0	Yellow inhibitor	Suppression of yellow blood and yellow cocoon
34	*I-a*	5.9	Dominant chocolate	Similar to chocolate mutation *(ch)*; head black
35	*bd*	6.7	dilute black	Whole larval body dilute black
36	*og*	7.4	giallo ascoli	High translucency; female almost sterile
				Linkage Group X
37	w_1(*w-1*)	0	white egg 1	No pigment in serosa; white eyes in moth
38	*fl*	0+	wingless	Fore and hind wings absent in pupa and moth
39	w_2(*w-2*)	3.4	white egg 2	Egg gradually changes from white to light reddish color; white eyes in moth
40	w_3(*w-3*)	6.9	white egg 3	Light purplish-brown egg; black eyes in moth
				Linkage Group XI
41	*K*	0	Knobbed	Dermal protuberances appear on dorsal sides of several segments of larva, pupa and moth
42	*Bu*	5.5	Burnt	Larva skin from 2nd to 5th segments shows burnlike scar
43	*bp*	17.1	black pupa	Black pupae (2 strains)
44	*mp*	24.0	micropterous	Small wings
				Linkage Group XII
45	*Ng*	0	No glue	Eggs easily separated from papers because of poor development of mucous glands in female
46	*C*	14.0	Golden egg	Cocoon golden yellow outside, nearly white inside
47	*rd*	52.1	clumpy	Irregular egg shape and highly variable
				Linkage Group XIII
48	*ch*	0	chocolate	Newly hatched larva reddish-brown
49	*cf*	11.3	crayfish	Fore and hind wings swollen and protrude laterally from body in pupa
				Linkage Group XIV
50	*Di*	0	Dirty	Irregular black lines and dots cover dorsal surface of larva
51	*U*	2.7	Ursa	Dark brown pigments cover dorsal and lateral sides of larva
52	*odk*	10.7	mottled	Low translucency
				Linkage Group XV
53	*Se*	0	White side egg	Egg surface irregular and with many furrows
54	*Gc*	7.8	Green c	Green cocoon

Contributors: (a) Novitski, E., (b) Kikkawa, H.

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6. LINKAGE GROUPS: PLANTS

Part I. NEUROSPORA CRASSA

Genes for *Neurospora crassa* are listed in order of locus on the chromosome; they proceed from left arm to right arm, with the CENTROMERE the dividing marker. A line under the symbol indicates that the exact position has not been determined. Bracket (}) signifies no recombination between loci. Capital letters in Columns A and B do not indicate dominant genes. A stable diploid, necessary for testing dominance, has not been achieved with *Neurospora* to date.

	Gene Symbol (A)	Mutation (B)	Phenotypic Expression (C)	Reference (D)
			Linkage Group I[1]	
1	*fr*	Frost	Delicate branching and nonconidial aerial growth	31
2	*nit-2*	Nitrate-2	Does not reduce nitrate	33
3	*leu-3*	Leucine-3	Requires leucine	3,31
4	*leu-4*	Leucine-4	Requires leucine	13
5	*un(b39)*	Unknown (b39)	Grows at 25°C, not at 34°C; distal to *A/a*; not tested for allelism with *un(55701)*	21
6	*un(55701)*	Unknown (55701)	Unknown requirement; strain *55701t* grows at 25°C, but not on minimal medium at 35°C	3,16,18
7	*A/a* }	Sex	Mating type	3,31
8	*dot* }	Dot	Restricted colonial growth (data scanty)	33
9	*pat*	Patch	Circadian rhythm of dense and sparse mycelial growth; location proximal to *A/a*	39
10	*phen*	Phenylalanine	Requires phenylalanine or leucine, or other aromatic amino acids; location uncertain with respect to *ad-5*	2
11	*ad-5*	Adenine-5	Requires adenine	3,31,33
12	*amyc*	Amycelial	Growth budding; forms dot-like colonies; location proximal to *ad-5*	18,31
13	*arg-1*	Arginine-1	Requires arginine; does not utilize ornithine or citrulline	31
14	*arg-3*	Arginine-3	Requires arginine or citrulline; does not utilize ornithine	3,31
15	*ti*	Tiny	Very restricted colonial growth	30,31
16	*suc*	Succinic	Requires succinic acid or metabolically related compounds; closely linked to centromere	3
17	*cyt-1*	Cytochrome-1	Slow growth; altered cytochrome system; shows 5% recombination with *suc*	25
18	*sn*	Snowflake	Conidiating colonial; location between *arg-3* and *hist-2*	23
	CENTROMERE			
19	*hist-2*	Histidine-2	Requires histidine	44
20	*rg*	Ragged	Poor conidiation; colonial growth	31
21	*lys-4*	Lysine-4	Requires lysine	3,31,44
22	*hist-3*	Histidine-3	Requires histidine	3,44
23	*ad-3*	Adenine-3	Requires adenine; accumulates purple pigment on limiting adenine	3,5,6,31,36
24	*cut*	Cut	Tube culture appears as if mycelia were cut off part way up slant; location between *hist-2* and *arg-6*	21
25	*nic-2*	Nicotinic-2	Requires nicotinamide; accumulates red-brown pigment in the medium	3,31
26	*cr*	Crisp	Early uniform conidiation	3,31
27	*m-1*	Modifier of *vis(3717)*	Location proximal to *vis(3717)*	17
28	*vis(3717)*	Visible (3717)	Semi-colonial growth (located on right arm)	3,17
29	*m-2*	Modifier of *vis(3717)*	Location distal to *vis(3717)*	17
30	*st*	Sticky	Can only be scored by direct comparison with wild type; location between *hist-2* and *thi-1*	31
31	*un(44409)*	Unknown (44409)	Unknown requirement; strain *44409t* grows at 25°C on complete medium, but not at 34°C	3,31
32	*slo*	Slow	Slow growth; location proximal to *thi-1*	31
33	*thi-1*	Thiamine-1	Requires thiamine	3,31
34	*mac*	Methionine-adenine-cysteine	Requires methionine; grows best on all 3 substances or complete medium; location between *thi-1* and *al-2*	31
35	*me-6*[2]	Methionine-6	Requires methionine	3,27,31
36	*csh*	Cushion	Restricted colonial growth; location between *thi-1* and *nit-1*	36
37	*nit-1*[3]	Nitrate-1	Does not reduce nitrate	3,31,40
38	*un(STL6)*	Unknown (STL6)	Suboptimal response to methionine; best scored at 35°C; fluffy morphology with late conidiation	31
39	*arg-6*	Arginine-6	Requires ornithine, citrulline, or arginine	3,31

/1/ Other markers known to be in Linkage Group I but presumably lost: *pa*--pale--conidia clumped and pale in color; *nd*--natural death--growth ceases progressively when fungus is homocaryotic; *dir*--dirty--conidia misshapen and few, yellow exudate; *gap*--gap--conidia produced in upper part of culture tube. [3] /2/ Called *me(35809)* in reference 3. /3/ Called *n-nit* in references 3 and 40.

continued

6. LINKAGE GROUPS: PLANTS

Part I. NEUROSPORA CRASSA

	Gene Symbol (A)	Mutation (B)	Phenotypic Expression (C)	Reference (D)
			Linkage Group I	
40	*T*	Tyrosinase thermostability	T^S and T^L govern tyrosinase thermostability; location between *hist-2* and *al-2*	15
41	*su-1-me*	Suppressor-1-methionine	Suppresses *me-2* and *me-7*; shows 1% recombination with *al-2*	3
42	*al-2*	Albino-2	Albino	3,31
43	*aur*	Aurescent	White at first; later forms pigmented terminal conidia	3,31
44	*hs*	Homoserine	Requires homoserine	3,31
45	*can*[4]	Canavanine	Resistance to canavanine	3,31-33
46	*lys-3*	Lysine-3	Requires lysine	3,31,35
47	*nic-1*[5]	Nicotinic-1	Requires nicotinamide	35
48	*os*	Osmotic	Inhibited by high osmotic pressure; can be scored by appearance; conidia rare	31
49	*so*	Soft	Dense pigmented growth in lower part of slant	31
			Linkage Group II	
50	*cfl*	Cauliflower	Dense conidiation in bunches at top of slant	33
51	*thr-2*	Threonine-2	Requires threonine; leaky	8,27,33
52	*thr-3*	Threonine-3	Requires threonine; extremely close to *thr-2*; leaky	33
53	*bal*	Balloon	Restricted growth; hemispherical colony	14,31
	CENTROMERE			
54	*da*	Dapple	Flecks of conidia on agar surface; location uncertain with respect to *bal* and centromere	33
55	*arg-5*	Arginine-5	Requires ornithine, citrulline, or arginine	3,31
56	*arom-3*	Aromatic-3	Requires phenylalanine, tyrosine, tryptophan, and *p*-aminobenzoic acid; does not use shikimic acid	14
57	*cpt*	Carpet	Flat growth on agar slants; location uncertain with respect to *arom-3*	33
58	*pe*	Peach	Peach-colored conidia (*see* line 64)	3
59	*su-pe*	Suppressor of microconidial	Suppresses microconidial action of pe^m in *col-1*, pe^m genotype; location 14-22 map units from *pe*	12
60	*arom-1*	Aromatic-1	Requires phenylalanine, tyrosine, tryptophan, and *p*-aminobenzoic acid; grows on shikimic acid	3
61	*arom-4*	Aromatic-4	Requires phenylalanine, tyrosine, tryptophan, and *p*-aminobenzoic acid; does not use shikimic acid	14
62	*ac-1*	Acetate-1	Requires acetate plus ethanol	3
63	*tu*	Tuft	Conidia in large clusters at top of culture; location between *pe* and *fl*	3
64	*fl*	Fluffy	No macroconidia; few or no microconidia; *pe fl* genotype forms abundant microconidia	3
65	*tryp-3*[6]	Tryptophan-3	Requires tryptophan; does not use indole	3
66	*het-2*	Heterocaryon formation	Determines heterocaryon compatibility; alleles *d*, *D*	11
			Linkage Group III	
	CENTROMERE			
67	*thi-4*	Thiamine-4	Requires thiamine; location uncertain with respect to *sc*	3
68	*thi-lo*	Modifier of *thi-1*	In presence of *thi-lo*, *thi-1* requires intact thiamine; may be allelic with *thi-4*	7
69	*sc*	Scumbo	Flat, irregular, concentric growth	3
70	*mel-3*	Melon-3	Forms hemispherical colony; location uncertain with respect to centromere and markers *thi-4* to *leu-1*	26
71	*ser-1*	Serine-1	Requires serine; can use glycine; very leaky	3
72	*prol-1*	Proline-1	Requires proline; will not use ornithine, citrulline, or arginine	3
73	*com*	Compact	Small colonies	31,34
74	*me-8*	Methionine-8	Requires methionine	28
75	*ad-4*	Adenine-4	Requires adenine; will not use hypoxanthine	3,34
76	*leu-1*	Leucine-1	Requires leucine	3,34
77	*su-mel-3*	Suppressor-melon-3	A loose colonial results from interaction of *mel-3* and *su-mel-3*; location distal to *leu-1*	26
78	*hist-7*	Histidine-7	Requires histidine; located between *ad-4* and *tryp-1*	44
79	*ad-2*	Adenine-2	Requires adenine or hypoxanthine	3,33,34

/4/ Called *r-can* in reference 3. /5/ Also called *Q*. /6/ Also called *td*.

continued

6. LINKAGE GROUPS: PLANTS

Part I. NEUROSPORA CRASSA

	Gene Symbol (A)	Mutation (B)	Phenotypic Expression (C)	Reference (D)
			Linkage Group III	
80	*tryp-1*	Tryptophan-1	Requires indole or tryptophan; accumulates yellow pigment	3
81	*thi-2*	Thiamine-2	Requires intact thiamine	3,34
82	*ro-2*	Ropy-2	Cable-like aggregations of hyphae; location between *tryp-1* and *vel*	31,34
83	*vel*	Velvet	Soft, conidiating colonial	31,34
84	*tyr-1*	Tyrosine-1	Requires tyrosine; very leaky	3,34
			Linkage Group IV	
	CENTROMERE			
85	*pyr-1*	Pyrimidine-1	Requires pyrimidine; uridine and cytidine 10-60 times as active as uracil	3,22,24
86	*pdx-1*	Pyridoxine-1	Requires pyridoxine	3,22,24
87	*pdx-2*	Pyridoxine-2	Requires pyridoxine	3
88	*rib-2*	Riboflavin-2	Requires riboflavin; location between *pdx-1* and *pyr-3*	3,22
89	*arg-2*	Arginine-2	Requires arginine; also uses citrulline	3,24
90	*col-4*[7]	Colonial-4	Colonial, macroconidial	3,22,24
91	*me-1*	Methionine-1	Requires methionine; location between *pdx-1* and *pyr-3*	3,28
92	*pyr-3*	Pyrimidine-3	Requires pyrimidine (*see* line 85)	3,24
93	*pt*	Phenylalanine-tyrosine	Requires phenylalanine plus tyrosine; location uncertain with respect to *pyr-3*; accumulates brown pigment in medium on aging; fluoresces under ultraviolet light	22
94	*tryp-4*	Tryptophan-4	Requires indole or tryptophan; location between *pdx-1* and *pan-1*	3,22
95	*leu(37501)*	Leucine (37501)	Requires leucine; location between *pdx-1* and *pan-1*	22
96	*ad-6*	Adenine-6	Requires adenine; location between *pdx-1* and *pan-1*	3,22
97	*me-2*	Methionine-2	Requires methionine; location between *tryp-4* and *pan-1*	3,22,28
98	*fld*	Fluffyoid	Aconidial; location proximal to *pan-1*	33
99	*thi-5*	Thiamine-5	Requires thiamine; shows 1% recombination with *pan-1*	33
100	*pan-1*	Pantothenic-1	Requires pantothenic acid	3,22
101	*ro-1*	Ropy-1	Cable-like aggregations of hyphae	22,31
102	*nit-3*[8]	Nitrate-3	Does not reduce nitrate; shows 13% recombination with *pan-1*	16,33
103	*chol-1*	Choline-1	Requires choline; location between *ad-6* and *me-5*	3,22
104	*col-1*	Colonial-1	Colonial growth; distal to *chol-1*	3
105	*cot*	Colonial-temperature sensitive	Colonial growth at 34°C; may be allelic with *col-1*	22,24
106	*ol*	Oleic acid	Requires higher fatty acid: lauric or larger, or Tween 80	33
107	*le-1*	Ascospore lethal	Colonial growth; location distal to *cot*	26
108	*hist-4*	Histidine-4	Requires histidine	22
109	*me-5*	Methionine-5	Requires methionine	3,22,24,34
110	*pyr-2*	Pyrimidine-2	Requires pyrimidine (*see* line 85)	3,22
111	*dn*	Dingy	Gray lumps, presumably microconidia, on agar slants	24
112	*mat*	Mat	Colonial; grows better on sucrose than on glycerol; location distal to *pyr-2*	22,31
			Linkage Group V	
	CENTROMERE			
113	*lys-1*	Lysine-1	Requires lysine; location uncertain with respect to centromere	3
114	*sh*	Shallow	Spreading morphological; hyphae on surface of agar slant; location uncertain with respect to *lys-1*	33
115	*iv-1*	Isoleucine-valine-1	Requires isoleucine and valine	3
116	*val*	Valine	Requires valine	43
117	*iv-2*	Isoleucine-valine-2	Requires isoleucine and valine; location uncertain with respect to *iv-1* and *val*	3
118	*lys-2*	Lysine-2	Requires lysine; location between *lys-1* and *hist-1*	42,43
119	*sp*	Spray	Aerial mycelium fans outwards	31,43
120	*arg-4*	Arginine-4	Requires arginine; also uses ornithine or citrulline; may be allelic with *arg-7*; location between *sp* and *inos*	3,33,37
121	*arg-7*	Arginine-7	Requires arginine; also uses ornithine or citrulline; may be allelic with *arg-4*	3,33,37
122	*am*	Amination-deficient	Requires α-amino nitrogen; leaky	9,31

/7/ Called *co* in reference 24. /8/ Called *nitr* in reference 16.

continued

6. LINKAGE GROUPS: PLANTS

Part I. NEUROSPORA CRASSA

	Gene Symbol (A)	Mutation (B)	Phenotypic Expression (C)	Reference (D)
	Linkage Group V			
123	*i*	Enhancer of *am*	Inhibits growth of *am* on medium containing inorganic nitrogen plus glutamic acid; shows 8% recombination with *am*	10
124	*wa*	Washed	Thin, spreading surface growth and conidiation; location between *lys-2* and *inos*	33
125	*hist-1*	Histidine-1	Requires histidine	3,43
126	*inos*	Inositol	Requires inositol	3,43
127	*arg-8*	Arginine-8	Requires arginine; data scanty	33
128	*pab-1*	para-Aminobenzoic acid-1	Requires *p*-aminobenzoic acid	3,43
129	*me-3*	Methionine-3	Requires methionine	3,43
130	*bis*	Biscuit	Conidiating colonial	31,43
131	*ser-2*	Serine-2	Requires serine; very leaky	33
132	*ad-7*	Adenine-7	Requires adenine	42,43
133	*pab-2*	para-Aminobenzoic acid-2	Requires *p*-aminobenzoic acid	43
134	*asp*	Asparagine	Requires asparagine	3,43
135	*pl*	Plug	Dense hyphae filling tube	31,43
	Linkage Group VI[9]			
136	*ad-8*	Adenine-8	Requires adenine; far out on left arm	19
137	*cyt-2*	Cytochrome-2	Slow growth; altered cytochrome system	38
138	*asco*	Ascospores colorless	Low germination; requires lysine; *lys-5(DS6-85)* is an allele of *asco*	38,41
139	*un(66204t)*	Unknown (66204)	Strain *66204t* does not grow on minimal medium at 35°C	3,38
140	*cys-2*	Cysteine-2	Requires cysteine or methionine (alleles designated *cys-c*, *cys-t* in reference 39)	38,39
141	*cys-1*	Cysteine-1	Requires cysteine or methionine	3,38
142	*ylo*	Yellow	Yellow conidia	3,38
143	*ad-1*	Adenine-1	Requires adenine	3,4,38
	CENTROMERE			
144	*pan-2*	Pantothenic-2	Requires pantothenic acid	4
145	*rib-1*	Riboflavin-1	Requires riboflavin at 35°C; location uncertain with respect to *pan-2* and *del*	3,38
146	*del*	Delicate	Growth less than that of wild type	20,31
147	*tryp-2*	Tryptophan-2	Requires anthranilic acid, indole, or tryptophan; leaky	3,38
	Linkage Group VII			
148	*nic-3*	Nicotinic-3	Requires nicotinamide	31,33
	CENTROMERE			
149	*sfo*	Sulfonamide	Requires sulfonamide; location uncertain with respect to centromere	3
150	*thi-3*	Thiamine-3	Requires thiamine; leaky; best scored on agar slants after several days	3,31
151	*bn*	Button	Colonial; nonconidiating	31
152	*me-9*	Methionine-9	Requires methionine; leaky	29
153	*me-7*	Methionine-7	Requires methionine; proximal to *arg-11*	33
154	*col-2*	Colonial-2	Colonial; nonconidiating	1,3,33
155	*col-3*	Colonial-3	Colonial; nonconidiating	1,3,33
156	*thr-1*	Threonine-1	Requires threonine; proximal to *arg-11*	33
157	*wc*	White collar	No carotenoids except at low temperature; proximal to *arg-11*	33
158	*for*	Formate	Requires formate or adenine plus methionine; proximal to *arg-11*	33
159	*arg-11*	Arginine-11	Requires arginine, adenine, and uridine	31
160	*arg-10*	Arginine-10	Requires arginine; does not use ornithine or citrulline	31
161	*nt*	Nicotinic-tryptophan	Requires nicotinamide or tryptophan	3,31
162	*sk*	Skin	Flat growth; nonconidiating	31

[9] Also known to be in Linkage Group VI but presumably lost: *phen(38602)*--phenylalanine (38602)--requires phenylalanine. [2,16]

Contributors: Barratt, R. W., and Strickland, W. N.

continued

6. LINKAGE GROUPS: PLANTS

Part I. NEUROSPORA CRASSA

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Part II. CHLAMYDOMONAS REINHARDI

Genes for *Chlamydomonas reinhardi* are listed in order of locus on the chromosome; they proceed from left arm to right arm, with the CENTROMERE the dividing marker. In those linkage groups with genes mapped in only one arm of the chromosome, the CENTROMERE is listed first. A line under the gene symbol indicates that the exact position has not been determined. Bracket (}) signifies no recombination between loci. Lower case letters in column A do not necessarily indicate recessive genes.

	Gene Symbol (A)	Mutation (B)	Phenotypic Expression (C)	Reference (D)
	Linkage Group 1			
1	*ac-209*	Acetate-209	Requires acetate	5
	CENTROMERE			
2	*ac-76*	Acetate-76	Requires acetate	5
3	*arg-1*	Arginine-1	Requires arginine, citrulline, or ornithine	1-4
4	*ac-14*	Acetate-14	Requires acetate	3
5	*arg-2*	Arginine-2	Requires arginine; does not utilize citrulline or ornithine	2-4
6	*pab-2*	*p*-Aminobenzoic-2	Requires *p*-aminobenzoic acid	2-4
7	*ac-115*	Acetate-115	Requires acetate; does not fix CO_2; shows 0.5% recombination with *pab-2*	7
8	*pf-4*	Paralyzed-4	Cells with paralyzed flagella	5
9	*thi-3*	Thiamine-3	Requires thiamine or thiazole	2-4

continued

6. LINKAGE GROUPS: PLANTS

Part II. CHLAMYDOMONAS REINHARDI

	Gene Symbol (A)	Mutation (B)	Phenotypic Expression (C)	Reference (D)
			Linkage Group II	
10	*thi-9*	Thiamine-9	Requires thiamine	5
	CENTROMERE			
11	*ac-12*	Acetate-12	Requires acetate	3
12	*pf-12*	Paralyzed-12	Cells with paralyzed flagella	3
13	*pf-18*	Paralyzed-18	Cells with paralyzed flagella	3
14	*nic-2*	Nicotinic-2	Requires nicotinamide	3,4
			Linkage Group III	
15	*pf-15*	Paralyzed-15	Cells with paralyzed flagella	3
16	*ac-28*	Acetate-28	Requires acetate; shows 0.6% recombination with *pf-15*	3
17	*pf-5*	Paralyzed-5	Cells with paralyzed flagella; shows 0.5% recombination with *pab-1*	5
18	*pab-1*	*p*-Aminobenzoic-1	Requires *p*-aminobenzoic acid	3,4
19	*ac-26*	Acetate-26	Requires acetate	5
	CENTROMERE			
20	*ac-17*	Acetate-17	Requires acetate; closely linked to centromere	3
21	*ac-141*	Acetate-141	Requires acetate; does not fix CO_2	7
22	*thi-2*	Thiamine-2	Requires thiamine or thiazole plus pyrimidine	3,4
			Linkage Group IV	
23	*nic-11*	Nicotinic-11	Requires nicotinamide	3
	CENTROMERE			
24	*thi-4*	Thiamine-4	Requires thiamine or thiazole	3,4
25	*pf-20*	Paralyzed-20	Cells with paralyzed flagella	3
26	*ac-55*	Acetate-55	Requires acetate; colonies yellow	5
			Linkage Group V	
27	*ac-31*	Acetate-31	Colonies yellow	3
28	*thi-8*	Thiamine-8	Requires thiamine or pyrimidine	3
29	*ac-18*	Acetate-18	Requires acetate	5
	CENTROMERE			
30	*pf-1*	Paralyzed-1	Cells with paralyzed flagella	3
			Linkage Group VI	
31	*mt*	Mating type	Mating type plus or minus	3
32	*nic-7*	Nicotinic-7	Requires nicotinamide	3,4
33	*thi-10*	Thiamine-10	Requires thiamine	5
34	*ac-29*	Acetate-29	Colonies yellow	5
	CENTROMERE			
35	*pf-14*	Paralyzed-14	Cells with paralyzed flagella	3
			Linkage Group VII	
36	*ac-6*	Acetate-6	Requires acetate	5
	CENTROMERE			
37	*pf-17*	Paralyzed-17	Cells with paralyzed flagella	3
38	*ac-1*	Acetate-1	Requires acetate; colonies almost white	3,4
39	*ac-22*	Acetate-22	Requires acetate; grows slowly; colonies pale green	5
40	*ac-5*	Acetate-5	Requires acetate; grows slowly; colonies pale yellow	5
			Linkage Group VIII	
41	*pf-3*	Paralyzed-3	Cells with paralyzed flagella	5
42	*thi-1*	Thiamine-1	Requires intact thiamine	3,4
	CENTROMERE			
43	*ac-157*	Acetate-157	Requires acetate	3,4
			Linkage Group IX	
44	*ac-51*	Acetate-51	Requires acetate	3
45	*pf-16*	Paralyzed-16	Cells with paralyzed flagella	3
46	*sr-1a*	Streptomycin-1a	Resistance to streptomycin; allelic with *sr-1*[1]	5,8
	CENTROMERE			
47	*ac-15*	Acetate-15	Requires acetate	3
48	*pf-13*	Paralyzed-13	Cells with paralyzed flagella	3

/1/ Consult reference 8.

continued

6. LINKAGE GROUPS: PLANTS

Part II. CHLAMYDOMONAS REINHARDI

	Gene Symbol	Mutation	Phenotypic Expression	Reference
	(A)	(B)	(C)	(D)
			Linkage Group X	
	CENTROMERE[a]			
49	*ac-16*	Acetate-16	Requires acetate; does not fix CO_2	3,7
50	*pf-19*	Paralyzed-19	Cells with paralyzed flagella	3
51	*pf-6*	Paralyzed-6	Cells with paralyzed flagella	5
52	*nic-13*	Nicotinic-13	Requires nicotinamide	5
			Linkage Group XI	
	CENTROMERE			
53	*pf-2*	Paralyzed-2	Cells with paralyzed flagella	3
54	*ac-7*	Acetate-7	Requires acetate; colonies yellow-green	5
55	*ac-21*	Acetate-21	Requires acetate; does not fix CO_2	3,6

/a/ Sequence may be: CENTROMERE, *nic-13*, *pf-6*, *pf-19*, *ac-16*.

Contributors: Ebersold, W. T., and Levine, E. E.

References: [1] Ebersold, W. T. 1956. Am. J. Botany 43:408. [2] Ebersold, W. T., and R. P. Levine. 1959. Z. Vererbungslehre 90:74. [3] Ebersold, W. T., et al. 1962. Genetics 47:531. [4] Eversole, R. A. 1956. Am. J. Botany 43:404. [5] Levine, E. E. Unpublished. Harvard Univ., Cambridge, 1963. [6] Levine, R. P. 1960. Proc. Natl. Acad. Sci. U.S. 46:972. [7] Levine, R. P., and D. Volkmann. 1961. Biochem. Biophys. Res. Commun. 6:264. [8] Sager, R. 1954. Proc. Natl. Acad. Sci. U.S. 40:356.

Part III. CORN

The genes in each linkage group for *Zea mays* are carried by the corresponding chromosome, e.g., linkage group 1, chromosome 1; linkage group 11, chromosome 2, etc. Capital letters (columns A and C) indicate dominant genes.

	Gene Symbol	Locus	Mutation	Phenotypic Expression
	(A)	(B)	(C)	(D)
				Linkage Group 1
1	*sr*	0	striate	Leaves striated
2	ga_6	15	gametophyte factor	Gametophyte viability
3	zb_4	21	zebra striping	Leaves with alternating transverse bands of green and whitish sectors
4	ms_{17}	25	male sterile	Male sterile
5	ts_2	27	tassel seed	Terminal inflorescence with pistillate flowers
6	*P*	28	Pericarp	Pericarp color
7	*zl*	30	zygotic lethal	Lethal zygote
8	*as*	53	asynaptic	Chromosomes unpaired at meiosis
9	*hm*	66	*Helminthosporium* susceptibility (recessive)	Susceptible to *Helminthosporium* infection
10	*br*	80	brachytic	Stalk has short internodes
11	*Vg*	84	Vestigial glumes	Glumes underdeveloped
12	f_1	85	fine striped	Fine striped, green and white leaves
13	an_1	107	anther ear	Stamens develop in pistillate inflorescence
14	*Kn*	128	Knotted leaves	Wartlike growths on leaves and stalk
15	gs_1	134	green striped	Leaves with light green stripes between vascular bundles
16	Ts_6	157	Tassel seed	Terminal inflorescence with pistillate flowers
17	bm_2	161	brown midrib	Brown pigment in leaf midrib
				Linkage Group II
18	ws_3	0	white sheath	Leaf sheaths and stalk deficient in chlorophyll
19	*al*	4	albescent	Seedlings become whitish
20	lg_1	11	liguleless	Absence of ligule on leaves

continued

6. LINKAGE GROUPS: PLANTS

Part III. CORN

	Gene Symbol	Locus	Mutation	Phenotypic Expression
	(A)	(B)	(C)	(D)
				Linkage Group II
21	gl_2	30	glossy seedling	Seedlings smooth and shining
22	*B*	49	Anthocyanin booster	Increases anthocyanin pigments
23	*sk*	56	silkless	Ears without silks
24	fl_1	68	floury endosperm	Endosperm powdery
25	ts_1	74	tassel seed	Terminal inflorescence with pistillate flowers
26	v_4	83	virescent	Young seedlings deficient in chlorophyll
27	*Ch*	1..8	Chocolate	Chocolate pericarp
				Linkage Group III
28	cr_1	0	crinkly leaves	Leaves crinkled
29	d_1	18	dwarf	Abnormally undersized
30	*rt*	32	rootless	Lacking roots
31	lg_3	38	Liguleless	Absence of ligule on leaves
32	*Rg*	40	Ragged leaves	Leaves appear split and torn due to development of necrotic areas
33	ts_4	47	tassel seed	Terminal inflorescence with pistillate flowers
34	ba_1	64	barren stalk	No ear produced
35	na_1	75	nana (dwarf)	Abnormally undersized
36	a_1	103	anthocyanin	Anthocyanin pigments present
37	sh_2	103.0+	shrunken endosperm	Endosperm shrunken
38	*et*	115	etched endosperm	Endosperm etched
39	ga_7	121	gametophyte factor	Gametophyte viability
				Linkage Group IV
40	de_1	0	defective endosperm	Endosperm defective
41	Ga_1	35	Gametophyte factor	Gametophyte viability
42	Ts_5	56	Tassel seed	Terminal inflorescence with pistillate flowers
43	sp_1	66	small pollen	Pollen of small size
44	su_1	71	sugary endosperm	Endosperm sugary
45	de_{16}	74	defective endosperm	Endosperm defective
46	zb_6	84	zebra striping	Leaves with alternating transverse bands of green and whitish sectors
47	*Tu*	100	Tunicate (pod corn)	Enlarged glumes in male and female inflorescences
48	j_2	105	japonica striping	Leaves green and white striped
49	gl_3	111	glossy seedling	Seedlings smooth and shining
				Linkage Group V
50	gl_{17}	0	glossy seedling	Seedlings smooth and shining
51	a_2	1	anthocyanin	Anthocyanin pigment present
52	bm_1	7	brown midrib	Brown pigment in leaf midrib
53	bt_1	8	brittle endosperm	Endosperm brittle
54	v_3	11	virescent	Young seedlings deficient in chlorophyll
55	*bv*	13	brevis (dwarf) plant	Undersized
56	*pr*	32	red aleurone color	Aleurone red
57	*ys*	41	yellow stripe	Leaves green and yellow striped
58	v_2	73	virescent	Young seedlings deficient in chlorophyll
				Linkage Group VI
59	*po*	0	polymitotic	Spores undergo extra meiotic-like divisions; male sterile
60	*Y*	13	Yellow endosperm	Endosperm yellow
61	pg_{11}	33	pale green	Light green seedlings and plants
62	*Pl*	44	Purple plant	Plant purple
63	*Bh*	45	Blotched aleurone	Aleurone blotched
64	*sm*	54	salmon silk	Salmon-colored silk
65	*py*	64	pigmy	Dwarf plant
				Linkage Group VII
66	o_2	0	opaque endosperm	Endosperm opaque
67	*in*	4	intensifier of aleurone color	Color of aleurone intensified
68	v_5	8	virescent	Young seedlings deficient in chlorophyll
69	ra_1	22	ramosa	Branching of ear and tassel
70	gl_1	26	glossy seedling	Seedlings smooth and shining
71	*Tp*	36	Teopod	Plant with many tillers and narrow leaves; ears and tassels have enlarged bracts

continued

6. LINKAGE GROUPS: PLANTS

Part III. CORN

	Gene Symbol (A)	Locus (B)	Mutation (C)	Phenotypic Expression (D)
				Linkage Group VII
72	*sl*	40	slashed leaves	Leaves slashed
73	*ij*	42	iojap	Leaves green and white striped
74	*Bn*	60	Brown endosperm	Endosperm brown
75	*bd*	96	branched silkless	Ears branched without silks
				Linkage Group VIII
76	v_{16}	0	virescent	Young seedlings deficient in chlorophyll
77	ms_8	14	male sterile	Male sterile
78	j_1	28	japonica striping	Leaves green and white striped
				Linkage Group IX
79	*Dt*	0	Dotted	Controller of a_2 mutability
80	yg_2	7	yellow-green	Seedlings and plants yellow-green
81	*C*	26	Aleurone color	Determines color of aleurone
82	sh_1	29	shrunken endosperm	Endosperm shrunken
83	*bz*	31	bronze	Aleurone and plant bronze
84	*bp*	44	brown pericarp	Brown pericarp
85	*wx*	59	waxy endosperm	Waxy endosperm
86	pg_{12}	66	pale green	Seedlings and plants light green
87	v_1	71	virescent	Young seedlings deficient in chlorophyll
88	bk_2	74	brittle stalk	Stalk brittle
89	*Wc*	106	White cap of endosperm	Cap of endosperm white
				Linkage Group X
90	*Rp*	0	Resistance to *Puccinia*	Resistance to *Puccinia* infection
91	*Og*	16	Old gold striping	Leaves green and yellow striped
92	*li*	28	lineate	Leaves with fine longitudinal striations
93	l_8	38	luteus seedling	Yellow seedlings
94	g_1	43	golden	Plant golden
95	*R*	57	Aleurone and plant color	Determines color of aleurone and plant

Contributor: Rhoades, M. M.

References: [1] Burnham, C. R. 1947. Maize Genet. Coop. News Letter 21:36. [2] Burnham, C. R. 1955. Ibid. 29:51. [3] Rhoades, M. M. 1950. J. Heredity 41:59. [4] Rhoades, M. M. 1955. In G. F. Sprague, ed. Corn and corn improvement. Academic Press, New York. pp. 123-219.

Part IV. TOMATO

Linkage groups for *Lycopersicon esculentum* do not correspond to similarly numbered chromosomes. Some linkage groups have not been assigned to a particular chromosome, while some chromosomes have not been given a linkage group number. Capital letters (columns A and C) indicate dominant genes.

	Gene Symbol (A)	Locus (B)	Mutation (C)	Phenotypic Expression (D)
				Linkage Group I (Chromosome 2)
1	*dv*	0	dwarf virescent	Stunted plants
2	*m*	3	mottled leaves	Leaves and cotyledons mottled
3	*d*	5	dwarf plant	Plant dwarfed; leaves dark and rugose
4	*p*	9	peach	Peach or pubescent fruit
5	*op*	13	opaca	Yellow-green patches on leaves
6	*dil*	17	dilute	Leaves light green
7	*ps*	20	positional-sterile	Positional-sterile flowers; prevents normal opening of corolla
8	*ro*	22	rosette	Rosette; very short internodes, no flowers

continued

6. LINKAGE GROUPS: PLANTS

Part IV. TOMATO

	Gene Symbol	Locus	Mutation	Phenotypic Expression
	(A)	(B)	(C)	(D)
	Linkage Group I (Chromosome 2)			
9	*O*	29	Oval fruit	Spherical, oblate, and elongate fruit
10	*aw*	30	without anthocyanin	No anthocyanin; stem green, not purple
11	*suf*	33	sufflava	Uniform light-green leaves
12	ms_{10}	35	male sterile-10	Pale anthers; exserted pistils; sterile
13	*bk*	36	beaked fruit	Sharp-pointed protuberance on blossom-end of fruit
14	*Cu*	38	Curl	Veins and petiole greatly foreshortened, leaves curled
15	*Me*	39	Mouse ears	Leaves pinnately compound, segments clavate
16	*wv*	42	white virescent	Plant virescent
17	*Wo*	48	Woolly plant	Woolly leaves and stems
18	*s*	53	compound inflorescence	Inflorescence much-branched; greatly increased number of flowers
19	*ne*	60	necrotic leaves	Necrotic leaf spots; leaves slowly killed
20	*Lc*	67	Few fruit locules	Fruits with only 2 or 3 locules
	Linkage Group II (Chromosome 3)			
21	*r*	0	yellow fruit flesh	Yellow flesh color
22	*wf*	15	white flower	White or tan corolla
	Linkage Group III (Chromosome 1)			
23	*br*	0	brachytic	Brachytic plants with short internodes
24	*y*	30	colorless fruit skin	Clear colorless skin on fruit
25	Cf_1	65	*Cladosporium* resistance	Resistance to races 1 and 3 of *Cladosporium fulvum*
	Linkage Group IV (Chromosome 6)			
26	*c*	0	potato leaf	Potato leaf; reduced number of leaf segments
27	*sp*	2	self-pruning (determinate habit)	Self-pruning or determinate stems
28	*md*	25	mottled-2	Small chlorotic spots on leaves
29	*Mi*	59	Nematode resistance	Resistance to *Meloidogyne incognita*
30	*yv*	60	yellow virescent	Leaves yellowish
31	Cf_2	61	*Cladosporium* resistance	Resistance to races 1-4 of *Cladosporium*
	Linkage Group V			
32	*bi*	0	bifurcata inflorescence	Branched inflorescence
33	*f*	2	fasciated fruit	Fasciated or many-loculed fruits
34	*a*	29	anthocyanin absent	Anthocyaninless; stems and leaves green, never purple
35	*hl*	49	hairless	Hairless plants; no hairs on hypocotyl
36	*gh*	54	ghost plants	Chlorophyll-deficient plants
37	j_1	69	jointless pedicel	Jointless pedicels
38	Cf_3	86	*Cladosporium* resistance	Resistance to races 1-4 of *Cladosporium*
	Linkage Groups VI and VIII (Chromosome 8)			
39	*al*	0	anthocyanin loser	Anthocyanin loser; purple stems become green in 10-21 days
40	*gf*	23	green flesh	Persistent chlorophyll in fruit
41	*dl*	40	dialytic stamens	Dialytic; stamens are not united in a tube
42	*bu*	49	bushy	Bushy stems; short internodes, long petioles
43	*ch*	65	chartreuse petals	Small, yellow-green corolla
44	l_1	76	lutescent foliage	Premature yellowing of leaves; yellowish unripe fruits
	(Chromosome 9)			
45	*wd*	0	wilty dwarf	Wilty dwarf plants; grayish-green, droopy leaves
46	*ah*	1.5	Hoffman's anthocyaninless (recessive)	Green stems
	Linkage Group VII (Chromosome 10)			
47	*pe*	0	sticky peel	Sticky fruit epidermis
48	*lg*	8	light green foliage	Light green foliage
49	*u*	43	uniform-ripening fruit	Uniform light-green color of unripe fruits; no dark shoulders
50	*H*	61	Hairs absent	Nonhairy or smooth stems; hypocotyl and growing point hairy
51	*nd*	72	netted	Leaves chlorotic with chlorophyll concentrated around veins
52	l_2	79	lutescent-2	Leaves turn yellow
53	*t*	92	tangerine fruit color	Flesh and stamens orange color
54	*Xa*	124	Xantha seedlings	Xanthophyllic or yellow leaves
55	*ag*	139	Andrus' green stem (recessive)	Green stem but purple cotyledons

continued

6. LINKAGE GROUPS: PLANTS

Part IV. TOMATO

	Gene Symbol	Locus	Mutation	Phenotypic Expression
	(A)	(B)	(C)	(D)
	Linkage Groups X and XII (Chromosome 7)			
56	*wt*	0	wilty foliage	Wilty leaflets; leaf margins curl adaxially
57	*tf*	15	trifoliate	Terminal leaflet tripartite
58	*n*	30	nipple-tipped fruit	Nipple tips on fruit
59	*mc*	46	macrocalyx	Sepals much enlarged
	Linkage Group XI (Chromosome 4)			
60	*e*	0	entire leaves	Entire or broad leaflets, as in Vilmorin's potato leaf
61	*di*	20	divergens	Leaf and stem color gray-green
62	w_1	28	wiry foliage	Wiry, slender, straplike leaflets; dwarfed plants
	Unnumbered Linkage Group A			
63	*rv*	0	reticulate virescent	Leaves virescent, veins prominent
64	*sf*	34	solanifolium	Potato-like leaves
	Unnumbered Linkage Group B			
65	*La*	0	Lanceolate	Entire, small leaves
66	*na*	28	nana	Tiny plants with short leaves

Contributors: (a) Butler, L., (b) Rick, Charles M.

References: [1] Butler, L. 1960. Can. J. Botany 38:365. [2] Butler, L. 1960. Tomato Genet. Coop. Rept. 10:5. [3] Rick, C. M., and L. Butler. 1956. Advan. Genet. 8:267.

7. GENETIC CODE

The nucleotide compositions of RNA codewords have been obtained by directing amino acids into protein in *Escherichia coli* extracts with randomly ordered polyribonucleotides synthesized with polynucleotide phosphorylase. Nucleotide sequence in codewords is not known, thus the order of bases is arbitrary. The tentative summary of RNA codewords shown in the table are considered to be *potential* codewords; that is, they code for amino acids in cell-free systems, but all codewords may not be applicable to cells in vivo.

	Amino Acid	RNA Codewords[1]					Amino Acid	RNA Codewords[1]			
	(A)	(B)					(A)	(B)			
1	Alanine	CCG	UCG[2]	ACG[2]		11	Leucine	UUG	UUC	UCC	UUA
2	Arginine	CGC	AGA	UGC[2]	CGA[2]	12	Lysine	AAA	AAU		
3	Asparagine	ACA	AUA	ACU[2]		13	Methionine	UGA			
4	Aspartic acid	GUA	GCA[2]	GAA[2]		14	Phenylalanine	UUU	CUU		
5	Cysteine	UUG				15	Proline	CCC	CCU	CCA	CCG[2]
6	Glutamic acid	GAA	GAU[2]	GAC[2]		16	Serine	UCU	UCC	UCG[2]	ACG
7	Glutamine	AAC	AGA	AGU[2]		17	Threonine	CAC	CAA		
8	Glycine	UGG	AGG	CGG		18	Tryptophan	GGU			
9	Histidine	ACC	ACU[2]			19	Tyrosine	AUU			
10	Isoleucine	UAU	UAA			20	Valine	UGU	UGA[2]		

/1/ Summary as of September, 1963. /2/ Probable codeword.

Contributor: Nirenberg, Marshall W.

References: [1] Nirenberg, M. W., et al. 1963. Cold Spring Harbor Symp. Quant. Biol. 28:549. [2] Speyer, J., et al. 1963. Ibid. 28:559.

8. CELL TYPES: SEED PLANTS

Because only approximate boundaries can be drawn between certain cell types in seed plants, the data have been restricted to the more salient and histologically apparent characteristics of the more common cell types. Spores, gametes, and many of the specialized cells have been omitted.

	Cell Type (A)	Specification (B)	Description (C)
1	Apical meristem	Origin	Lineal descendents of cells of embryo, except in adventitious shoots and roots
2		Site	Apices of vegetative shoots, developing inflorescences, and flowers; in root, beneath inner edge of root cap
3		Morphology	Cells polyhedral; primary wall thin or irregularly thickened; primary pit fields may be present; nucleus large, ovoid; cytoplasm vacuolated; mitochondria, plastid primordia, and storage products may be present
4		Function	Point of origin of primary meristematic tissues (protoderm, ground meristem, procambium) from which primary body of shoot and root develops; in shoot apex, gives rise to tissue of leaf primordia
5	Vascular cambium	Origin	Procambium, and parenchyma in interfascicular areas, cortex, and phloem
6		Site	Lateral in stem and root, between secondary xylem and secondary phloem
7		Morphology	Two types of cambial cells: elongated fusiform initials (from which tracheary elements, sieve elements, fibers, and vertical parenchyma are derived), and ray initials (from which vascular rays originate); cytoplasm in both cell types highly vacuolated; primary walls have conspicuous pit fields
8		Function	Produces secondary phloem and secondary xylem cells; growth in diameter of woody stems and roots results from tissue formation by cambial cells
9	Phellogen (cork cambium)	Origin	In stems, first phellogen cells arise from cortex (most commonly from outermost layer), or from epidermis or phloem parenchyma cells; in roots, from pericycle
10		Site	Lateral in stem and root, between phellem and subjacent phelloderm, cortical or phloem tissue; also beneath surface exposed by abscission of organs (leaf scars) or beneath wounds
11		Morphology	Cells rectangular and radially flattened in transectional view, polygonal or nearly isodiametric in longisection; walls thin, cytoplasm vacuolated; may contain tannins and chloroplasts
12		Function	Produces phellem cells outwardly and in many cases phelloderm cells inwardly; forms complementary tissue of lenticels
13	Epidermis	Origin	Protoderm
14		Site	Surface layer of foliar and floral organs; young stems and roots
15		Morphology	Cells polygonal, elongated, or with undulated contour in surface view; variable in radial dimensions; walls thin or thick, the outer wall often thicker; primary pit fields present; walls typically cutinized (may be lignified or silicified), the outer wall covered by cuticle except in roots; plastids, anthocyanin pigments, and ergastic substances may occur
16		Function	Mechanical protection; restriction of transpiration; storage of water and metabolic products; photosynthesis; water absorption in roots; by division and dedifferentiation may contribute to origin of adventitious shoots and roots
17	Guard cell	Origin	Typically originate in pairs by division of specific "mother cells" of the protoderm; (in many plants paired guard cells are flanked or surrounded by distinctive subsidiary cells)
18		Site	Epidermis of foliage leaves and young stems; occurs in the epidermis of various types of floral organs; absent from epidermis of roots
19		Morphology	Cells usually crescentic or kidney-shaped in surface view; walls unevenly thickened, cutinized and overlaid by cuticle; often with ridgelike extensions above and below pore; conspicuous starch-forming chloroplasts present; protoplast physiologically active in mature cells but rarely divides in response to wound or other stimuli
20		Function	A pair of guard cells and the intercellular space or pore between them form a stoma. Reversible changes in turgor of guard cells result in the opening or closure of the pore, permitting diffusion of gases through the epidermis.
21	Phellem (cork)	Origin	Phellogen; in stems of some monocotyledons, tangentially dividing cortical parenchyma cells produce irregular bands of suberized cells termed "storied cork"
22		Site	Peripheral regions of stem, root, and some fruits; occurs in bud scales and petioles; often produced as a result of wounding
23		Morphology	Cells rectangular in transection and radially flattened; irregular or rectangular in longisection; wall typically suberized and devoid of pits; nonliving at maturity; may contain resin and tannins
24		Function	Mechanical protection; restriction of transpiration
25	Parenchyma	Origin	Ground meristem, procambium, vascular cambium, and phellogen
26		Site	Dominant cell type in cortex, pith, mesophyll, fleshy fruits, and endosperm of seeds; occurs in phloem and xylem as component of vertical strands and vascular rays
27		Morphology	Cells approximately tetrakaidecahedral to elongated, or stellately branched; primary walls thin or thick, often with conspicuous pit fields; thick, lignified secondary walls with pits common in secondary xylem; plastids and a large number of ergastic substances present

continued

8. CELL TYPES: SEED PLANTS

	Cell Type	Specification	Description
	(A)	(B)	(C)
28	Parenchyma	Function	Photosynthesis; food and water storage; secretion and excretion; commonly the protoplast retains marked capacity for growth, division, and differentiation, and therefore is prominently concerned in wound healing, formation of callus tissue, and the origin of adventitious shoots and roots
29	Collenchyma	Origin	Ground meristem
30		Site	Sole component of cylinders or strands of tissue in the subepidermal portions of stems, petioles, and larger veins of leaves; may occur in root cortex
31		Morphology	Cells relatively short and prismatic, or elongated with tapering ends; primary walls unevenly thickened and composed of cellulose, pectin, and a high percentage of water; primary pit fields present; chloroplasts common; collenchyma and cortical parenchyma cells frequently intergrade in form and structure
32		Function	Mechanical support for growing stems and leaves; protoplast retains capacity for growth, division, and differentiation
33	Sclereid	Origin	Protoderm, ground meristem, phellogen, vascular cambium, and procambium; frequently arises by sclerosis of a fully developed parenchyma cell
34		Site	Common in seed coats and fruits; diffusely arranged (as idioblasts or as a component of cell clusters) in cortex, functioning phloem, outer bark, pith, and mesophyll; in leaves of some dicotyledons, sclereids are restricted to vein endings (terminal sclereids)
35		Morphology	Cells may be polyhedral, columnar, fusiform, filiform, irregularly lobed or branched; in some cases they intergrade in form with fibers; secondary wall thick and lignified (sometimes with imbedded crystals); pits usually simple, often ramiform; protoplast may be retained at maturity
36		Function	Produces hard, incompressible texture of many tissues
37	Fiber	Origin	Protoderm, ground meristem, procambium, and vascular cambium
38		Site	Cortex, primary and secondary vascular tissues of stem and root; epidermis of some leaves; component of hypodermal strands or layers and of the sclerenchymatous sheaths of vascular bundles in many kinds of leaves; cells may occur as idioblasts
39		Morphology	Typical prosenchymatous cell, frequently elongated; secondary wall usually thick, often highly lignified; pits abundant or scarce, simple or with greatly reduced borders; protoplast usually absent at maturity; a living protoplast and various ergastic materials occur in septate fibers; in secondary xylem of dicotyledons, fibers and tracheids frequently intergrade in form and structure
40		Function	Mechanical support
41	Tracheid	Origin	Procambium and vascular cambium
42		Site	Primary and secondary xylem; in a modified form, the distinctive cell type in transfusion tissue of gymnosperm leaves; in leaves of some angiosperms, tracheid-like cells, termed "storage tracheids," occur as idioblasts, as cells associated with veinlets, or as components of cell groups or layers; commonly formed in masses in cultures of callus tissue
43		Morphology	Cells imperforate, and typically elongated with blunt, tapering, or inclined ends; patterns of lignified secondary wall thickenings diversified and often intergrading (annular, helical, scalariform, reticulate, pitted); devoid of protoplast at maturity
44		Function	Conduction of water and mineral solutes; mechanical support
45	Vessel member	Origin	Procambium and vascular cambium
46		Site	Primary and secondary xylem of most dicotyledons; absent from xylem of all gymnosperms except members of the Gnetales; in some monocotyledons, restricted to primary xylem of root
47		Morphology	Cell form ranges from elongate to drum-shaped, with inclined or transversely oriented end walls; a series of superposed vessel members constitutes a vessel; perforation plates usually restricted to end walls and are either simple (one perforation) or multiperforated (scalariform, reticulate, or foraminate); secondary walls lignified (with same range of patterns as in tracheids); devoid of protoplast at maturity
48		Function	Conduction of water and mineral solutes; possibly furnishes mechanical support
49	Sieve cell	Origin	Procambium and vascular cambium
50		Site	Primary and secondary phloem of gymnosperms
51		Morphology	Cells elongated, with overlapping inclined or tapering ends; sieve areas numerous, uniform, and relatively undifferentiated; a sieve area is a portion of the primary wall, traversed by strands of cytoplasm, each strand enclosed in a cylinder of callose; protoplast enucleate at maturity; usually associated with certain ray and phloem-parenchyma cells termed "albuminous cells"
52		Function	Conduction of organic solutes
53	Sieve-tube member	Origin	Procambium and vascular cambium
54		Site	Primary and secondary phloem of angiosperms

continued

8. CELL TYPES: SEED PLANTS

	Cell Type	Specification	Description
	(A)	(B)	(C)
55	Sieve-tube member	Morphology	Cells elongated, with inclined or transverse end walls; a series of superposed sieve-tube members constitutes a sieve tube; end walls with highly specialized sieve areas termed sieve plates; sieve plates are either simple (one sieve area) or compound (several sieve areas in scalariform or reticulate arrangement); lateral walls usually bear less-differentiated sieve areas; protoplast enucleate at maturity; each sieve-tube member associated with one or more nucleate cells (companion cells) which are ontogenetically developed as daughter cells of the sieve-tube member
56		Function	Conduction of organic solutes
57	Laticifer	Origin	Nonarticulated laticifers originate from single cells in the embryo and grow intrusively throughout plant; articulated laticifers arise from interconnected series of cells in which partial or complete removal of certain walls occurs
58		Site	Cortex, secondary phloem and xylem, pith, mesophyll
59		Morphology	Nonarticulated type is either an unbranched tube or a profusely ramified system of nonseptate tubes; articulated laticifers may become joined by lateral anastomoses to form a complex network; primary walls nonlignified and often thick; both types contain latex and are multinucleate
60		Function	Probably largely excretory because of storage of such apparently nonfunctional metabolic products as resins and rubber; the role of laticifers as food-conducting or food-storing structures is doubtful

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9. TISSUE GROWTH CHARACTERISTICS: MAMMALS

	Tissue	Growth Feature	Growth Characteristics
	(A)	(B)	(C)
1	Adrenal	Division	Rat (adult), mitosis: zona capsula and zona fasciculata, 0.13% each; zona glomerulosa, 0.17%; zona reticularis, 0.06%; total gland, 0.12%. For young rat, percentages higher than for adult. [12, 73]
2		Mode of growth	Rat: Principally by cell division; capsule may contribute. [12]
3		Life span	Rat: In cortex, uncertain; phagocytosis occurs in zona reticularis. [12]
4		Replacement	Rat: In cortex, cell division and migration of cells from superficial to deeper layers [12, 73].
5		Regenerative capacity	Man, guinea pig: In cortex after damage, repair by cell division (limited in adult) [48]. Active regeneration follows postnatal degeneration. Man, rat: Mitosis scant in medulla; postnatal growth due to cell enlargement. [73, 85]
6	Alimentary canal	Division	Cat, stomach: Dividing cells at base of foveolae [49]. Rat: Dividing cells in crypts of duodenum and ileum; make up 3% of all cells; cycle, 1.13 hours. [64]
7		Mode of growth	Cell division and differentiation in mucous membrane. Muscle, by combination of cell division and increase in cell size. [75]
8		Life span	Rabbit, oral mucosa: 5.1(4.5-5.7)/1,000 cells; diurnal variation, 3.8(3.6-4.0) and 7.2(6.6-7.8). Mitotic duration calculated as 64 minutes. Intermitotic period calculated as 208 hours. [55] Rat, small intestine: 60-70% of superficial epithelium shed per day. Cell lives 1.57 days in duodenum, 1.35 days in ileum. [64]
9		Replacement	Cat: Cells multiply in crypts in base of foveolae, move toward lumen and differentiate [49].
10		Regenerative capacity	Cat: Brunner's glands can undergo limited regeneration [43]. Stomach: Movement at 0.2-0.4 mm/hr; epithelium, after sudden loss, restored in a few hours. [49] Dog, stomach: After removal of mucous membrane, denuded area covered by growth of undifferentiated epithelium at rate of 2 mm/wk [41].

continued

9. TISSUE GROWTH CHARACTERISTICS: MAMMALS

	Tissue (A)	Growth Feature (B)	Growth Characteristics (C)
11	Blood erythrocytes	Division	Confined largely to erythroblasts in bone marrow. Man, dividing cells: 1.17-1.83%. [76, 81]
12		Mode of growth	Rabbit, rat, chicken: In precursors, growth phase sharply separated from hemoglobin formation [86].
13		Life span	Man: 120 days most generally accepted [24].
14		Replacement	Man: 0.83% red cells replaced each day [24].
15		Regenerative capacity	Man: Recovery in 50 days from 600-ml blood loss [45]. Rabbit: Recovery in 3 weeks from 30% blood loss [18]. Rat: Recovery in 7 days from 30% blood loss [18].
16	Blood granulocytes	Division	Man: Confined largely to myeloblasts (2.7%) and myelocytes (0.46%) in bone marrow [81].
17		Mode of growth	Rabbit, rat, chicken: Growth stages sharply demarcated from stages of granule formation [86].
18		Life span	Man: Neutrophils estimated at 70-80 hours; eosinophils, 10-14 days. [58] Cat: Neutrophils disappear from blood at rate of 881/cu mm/hr [62].
19		Replacement	Cat: Replaced 1.5 times per day [62].
20	Blood lymphocytes	Division	In tissues of origin. Rat (3 months old), dividing cells: thymus, 0.22%; lymph nodes, 0.058%; lymph follicles in spleen, 0.058%. [5]
21		Mode of growth	Rabbit, marrow: Derived from reticulum cells and may be converted to other forms (?) [70]. Cat: 35 x 10^6 kg/hr enter circulation [2]. Dog: 25 x 10^6 kg/hr enter circulation [92].
22		Life span	Approximately 24 hours. Removed from blood by lungs (rat) [89], spleen (rabbit) [40], lymph glands (dog) [92], skin (rat) [6], intestine [51].
23		Replacement	Replacement in blood stream 2.06 times per day [2, 92, 93].
24		Regenerative capacity	Rabbit (young): Limited regeneration of lymph nodes after removal; mesenchyme cells form complete gland in 3-4 weeks. [46]
25	Blood platelets	Mode of growth	Evidence favors formation in marrow from cytoplasmic fragmentation of megakaryocytes [91].
26		Life span	Cat: 2-4 days; utilization, 2,500 cu mm blood/hr. [63]
27		Replacement	Dog: After loss, new formation begins in a few hours; normal level regained in 3-4 days. [87].
28	Brain and spinal cord	Division	Rat: Very rare but has been reported [4].
29		Mode of growth	Growth of axones, myelination of fiber tracts. May not be completed until 18th year in man. [34]
30		Life span	Coextensive with normal function [75].
31		Replacement	Confined to neuroglia [75].
32		Regenerative capacity	Cat: Preganglionic fibers in peripheral nerves regenerate in 36-61 days [56]; function restored in 44 days [47]. Very largely confined to neuroglia; some axone formation. Rabbit: Regeneration of motor axones occurs at 4 mm/da after latent period of ±7 days. [94]
33	Hair	Growth rate	Man: head, 2.7 mm/wk; arm, 1.5 mm/wk; face, 2.1-3.5 mm/wk. [38, 88]
34		Life cycle	Depends on thickness. Man: head, 3 years; eyebrow, 120 days. [23] Rat: body, 35 days [23].
35		Replacement	By multiplication and differentiation of cells at bottom of hair follicles [38, 88].
36	Heart	Mode of growth	Man (from birth to maturity): Diameter of muscle fibers increases 2.6 times (to 14 μ) [82]. Rabbit: Diameter of muscle fibers increases 2.6 times (to 19 μ) [82].
37		Life span	Coextensive with normal function [75].
38		Replacement	None [75].
39		Regenerative capacity	Negligible; hypertrophy caused by increase in size of fibers. Man: normal diameter, 14 μ; hypertrophied, 25 μ. [82] Rabbit: normal diameter, 19.2 μ; hypertrophied, 22.2 μ. [82]
40	Hypophysis	Division	Observed in normal animals. Occurs in anterior lobe after injury. Division stimulated when endocrine disturbances develop. Activity noted after administration of estrogen, testosterone, etc. [25]
41	Kidney	Division	Rare after early postnatal life, except for regeneration in rodents [75].
42		Mode of growth	Increase in size of cells and structures. Man (from birth to maturity): Diameter of glomerulus increases from 118 μ to 240 μ, diameter of proximal collecting tubules from 18-34 μ to 40-64 μ. [32, 59, 75] Rat: Early postnatal growth partially caused by peripheral, undifferentiated nephrogenic zone; number of nephrons doubles in first two weeks of life. [13, 75]
43		Life span	Very largely coextensive with normal function [75].
44		Replacement	By cell divisions in tubules [75].
45		Regenerative capacity	Rat: True regeneration observed; hypertrophy caused by enlargement of existing elements, but increased cell division demonstrated after unilateral nephrectomy. [25, 26]

continued

9. TISSUE GROWTH CHARACTERISTICS: MAMMALS

	Tissue	Growth Feature	Growth Characteristics
	(A)	(B)	(C)
46	Liver	Division	Rat: Dividing cells rise from low values to 3.3% on 23rd day, then return to low [19,66]. (Albino), mitosis: 0.005% [19].
47		Mode of growth	Rat: In early life, considerable contribution from cell division; later from increase in cell size. [66]
48		Life span	Rat: No figure available [66].
49		Replacement	Rat: Dividing cells persist in small numbers in adult, presumably to replace cell loss [66].
50		Regenerative capacity	Rat: Extirpation of two-thirds regenerated in 21 days, caused by cell division in parenchymal cells and, to a smaller extent, in duct cells; division also occurs in Kupffer's cells and connective tissue cells. [1]
51	Muscle, smooth	Division	Fibers retain some power of division [16].
52		Mode of growth	New formation possible from undifferentiated connective tissue cells [16].
53		Regenerative capacity	Regeneration after injury limited; fibrous scar usual. [16]
54	Muscle, striped	Division	Scant; confined to nuclei. Some amitotic division. [16]
55		Mode of growth	Enlargement and possible splitting of fibers. In newborn, some continued formation from mesenchyme cells. Hypertrophy caused by increase of sarcoplasm in preexisting cells. [16]
56		Life span	Coextensive with normal function [75].
57		Replacement	Normally none [75].
58		Regenerative capacity	Rabbit: Protoplasmic outgrowth from preexisting fibers in which nuclei may divide by amitosis. Outgrowth begins 3rd day after injury, progresses at 1-1.5 mm/da. New fibers 30% of normal diameter in 21 days; normal diameter in 4 months. No new formation from undifferentiated cells. [28, 31]
59	Nails	Mode of growth	Man, thumbnail: Daily increase of 95µ. (Fingernails grow 4 times as fast as toenails.) [30]
60	Ovary	Division	Rat: Mitosis demonstrated in germinal epithelium, and during pregnancy in granulosa and theca interna cells [11,37].
61		Mode of growth	Rabbit: Follicles increase in size exponentially with time; completed in 11 days. [35,36] Rat: Total number of oocytes in gland related to age; log (no.) = 4.561-0.476 log (age in days). [50, 67]
62		Life span	Fertility loss of shed ova: ferret, 30 hours; gu[illegible] 26 hours; rabbit, 12 hours. [53]
63		Regenerative capacity	Mouse: No regeneration of ova; marked regenerative activity of germinal epithelium after hormonal stimulation. [65]
64	Pancreas	Mode of growth	Man: Decrease in relative amount of connective tissue after birth; adult proportions reached at 11th-16th year. [39]
65		Regenerative capacity	Man, dog, guinea pig, rabbit: Limited amount after resection or duct ligation. Mitosis in acinar cells and duct epithelium, the latter giving rise to acinar and islet cells. [25]
66	Parathyroid	Division	Mouse, dividing cells: 8 days, 0.07%; 18 days, 0.71%; 28 days, 0.01%. [44]
67		Mode of growth	Multiplication of clear or stem cells which differentiate into "dark" cells [42, 44].
68		Regenerative capacity	Man: Negligible. Hypertrophy and hyperplasia in chronic nephritis. [3]
69	Prostate gland	Division	Rat, mitosis: Numerous up to 20th day, scant at 100 days [77].
70		Mode of growth	Man: During last months of pregnancy, fetal prostate shows proliferation and alteration of tubule epithelium, squamous metaplasia, cystic dilation of tubules, hyperplasia and dilation of ejaculatory ducts. These persist for 1-4 weeks after birth, then undergo gradual regression. [7, 25] Man, rat: Growth affected by hormonal activity [7,77,78]. Rat: By cell proliferation up to 20 days, then by increase in cell size and diameter of acini; from 11 to 55 days, height of cell increases from 18 µ to 34 µ, and diameter of acini from 43 µ to 170 µ. [77]
71		Regenerative capacity	Man: Regeneration very rare after surgical removal [25].
72	Salivary gland	Division	Rat, mitosis per 1,000 acinar cells: parotid, 1.02±0.23; sublingual, 0.70±0.23; submandibular, 0.64±0.17. Mitosis per 1,000 tubular cells: submandibular, 0.44±0.12. [27]
73		Life span	Rat, acinar cells: parotid, 41 days; sublingual, 60 days; submandibular, 65 days. Tubular cells: submandibular, 95 days. [27]
74		Replacement	Rat: By division of acinar or tubular cells [27,72].
75		Regenerative capacity	Rat: Slight regeneration by proliferation of acinar cells and of intercalated ducts [27,72].

continued

9. TISSUE GROWTH CHARACTERISTICS: MAMMALS

	Tissue	Growth Feature	Growth Characteristics
	(A)	(B)	(C)
76	Skin	Division	Mouse (newborn): 2-4% nucleated cells in mitosis [20, 33]. (8-16 weeks old): Mitotic cycle, 30.2±12 minutes [60]. (Adult): 2-8 dividing cells/cm length of 7-μ ear section [20, 33]. Mouse, rat: Occurs in varying proportions in stratum spinosum. Number of divisions varies with time of day, carbohydrate metabolism, hormonal stimulation, etc. [54] Rat (250 grams): Mitosis in the planta averages 5.24% for 24 hours at 27°C [84].
77		Mode of growth	Division of cells in deeper layers, followed by differentiation [75].
78		Life span	Rabbit, rat: Variable; dependent on rate of shedding of keratinized cells. [55, 84] Rat, plantar epidermis cells: 19.1 days, of which 16.9 days are spent in basal layer and 2.2 days in stratum granulosum [84]. Mitotic index for corneal epithelium, 0.4% [22].
79		Replacement	Mouse: Adjustment between cell loss and cell formation [21].
80		Regenerative capacity	Man: High capacity for regeneration and repair [29]; re-epithelization of wounds by proliferation and migration of adjacent cells [15, 28, 71]; regeneration possible from hair follicles [15]. Man, rat: Growth of granulation tissue checked by epithelium overgrowth [14, 15].
81	Submaxillary gland	Regenerative capacity	Rat: Regeneration by division of acinar cells in 1st week, followed by proliferation of ducts with acini formed from terminal portions [25].
82	Testis	Division	Rat (albino): Cycle of spermatogonal division, 48 minutes; spermatogenic wave lasts 4 days; spermatogenic cycle takes 16 days. [80]
83		Life span	Sperm survival time: man, 48-72 hours; horse, 12 hours; mouse, 13.5 hours; rabbit, 96 hours; bat, possibly through winter. [8, 9, 52, 83]
84		Regenerative capacity	Possible after slight injury. Rabbit: One day in abdominal cavity causes loss of spermatogenic elements; restoration in 2 weeks. [10]
85	Thymus	Division	Mitosis: rabbit (adult), 0.52%; rat (3 month old), 0.22%. [5]
86		Mode of growth	Develops from pharyngeal epithelium [42]. Man: Increases from birth to puberty, decreases in later life. Weight at birth, 12-15 g; at puberty, 30-40 g; at 60 years, 10-15 g. [16]
87	Thyroid	Division	Guinea pig: 100-125 dividing cells recorded in whole gland [17].
88		Mode of growth	Develops from pharyngeal epithelium [42]. Dog: Proliferation of interfollicular cells [95]. Rabbit: New follicles by budding [90].
89		Regenerative capacity	Man, dog, guinea pig: After partial removal, hypertrophy of remainder preventable by iodine administration [68, 69, 79].
90	Uterus	Mode of growth	Man, menstruation: In proliferative stage, mitosis in endometrium rises to 0.56%, and nuclei of muscle fibers increase in size; regression in secretory phase. [74] Epithelial cells spread from gland tubules over connective tissue of endometrium, covering denuded surface by 7th day [25]. Pregnancy: Enlargement of preexisting epithelial cells, glands, and muscle fibers; cell division of epithelial and muscle elements; new muscle fibers may form from undifferentiated cells. [16, 61]
91		Regenerative capacity	Mouse: Experimental incision healed in 48 hours without scar [57].

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10. CELL DIVISION FREQUENCY: MICROORGANISMS

For information on additional species, consult reference 1, Part I.

Part I. PROTOZOA

	Class	Species	Culture Medium	Temp. °C	Cell Divisions per Day	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
1	Ciliata	*Didinium nasutum*	Hopkins' medium + *Paramecium*	21	3.6	2
2		*Paramecium aurelia*	Lettuce + bacteria	20±	0.72	6
3			Lettuce + bacteria	28	2.02	6
4		*Stentor coeruleus*	Peters' medium + ciliates	19	0.6-0.9	4
5			Modified Peters' medium + ciliates	18-20	0.7-2.1	4
6			Hetherington's medium +*Blepharisma*	22	0.65	3
7	Mastigophora	*Chilomonas paramecium*	Sodium acetate + mineral salts	24	3.5	5
8		*Euglena gracilis*	Wheat infusion	25	3.5	7

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Part II. VIRUSES AND BACTERIA

Culture Medium (column B): MS = mineral salts; AM = allantoic membrane.

	Species	Culture Medium	Temp. °C	Generation Time min	Reference
	(A)	(B)	(C)	(D)	(E)
	Vira[1]				
1	Influenza A (PR-8)	AM, chick embryo	37	330-510	10
2	Influenza A (5 strains)	AM, chick embryo	37	300-360	14
3	Influenza B (3 strains)	AM, chick embryo	37	480-600	14
4	Swine influenza	AM, chick embryo	37	360	14
	Bacteriophyta[2]				
5	*Aerobacter aerogenes*	Broth or milk	37	18	16
6		Glucose + peptone	37	17.2-17.4	16
7		Peptone	37	22-30	16
8		Synthetic	37	29-44	9
9	*Azotobacter chroococcum*	Glucose broth	.....	27-39	16
10		MS + sugar	25-30	240-348	16
11		Sugar + urea	28	74	4
12	*Bacillus subtilis*	Glucose broth	.....	26-32	16
13	*Clostridium botulinum*	Glucose broth	37	35	23
14	*Corynebacterium diphtheriae*	Serum + glucose broth	37	34	16
15	*Diplococcus pneumoniae I*	Broth	37	24.5	2
16		Serum	37	29	1
17		Serum + broth	37	20.5	6
18	*D. pneumoniae II*	Broth	37	33	6
19		Glucose broth	37	30	15
20		Serum + broth	37	23	2

/1/ Generation time: the time required for infected cells to release new virus. /2/ Generation time: the average interval between cell divisions.

continued

10. CELL DIVISION FREQUENCY: MICROORGANISMS

Part II. VIRUSES AND BACTERIA

	Species	Culture Medium	Temp. °C	Generation Time min	Reference
	(A)	(B)	(C)	(D)	(E)
	Bacteriophyta[2]				
21	*Erwinia carotovora*	Broth	37	57	16
22		Glucose broth	37	42	16
23	*Escherichia coli*	Broth	37	16.5-17.0	22
24		Lactose broth	37	16	21
25		Milk	37	12.5	11
26	*Lactobacillus acidophilus*	Milk	37	66-87	16
27	*Mycobacterium tuberculosis*[3]	Synthetic	37	792-932	25
28	*Proteus vulgaris*	Broth	37	21.5	16
29		Peptone + phosphate	37	40	7
30	*Pseudomonas pyocyanea*	Broth	37	34	16
31		Glucose broth	37	31	16
32		Lactose broth	37	34	16
33	*Rhizobium leguminosarum*	MS + yeast + mannitol	25	79-187	5
34	*Salmonella typhosa*	Bile + pus	37	24.5	19
35		Broth	37	23.5	17
36		Glucose broth	37	29	8
37		Glucose + peptone	37	33	18
38	*Shigella dysenteriae*	Milk	37	23	13
39		Peptone + phosphate	37	37	7
40	*Staphylococcus aureus*	Broth	37	27	12
41		Glucose broth	37	32	16
42	*Streptococcus lactis*	Glucose milk	37	26	16
43		Lactose broth	30	48	16
44		Milk	37	26	20
45		Peptone milk	37	37	16
46	*Vibrio comma*	Broth	37	21.2-38.0	3
47	*Xanthomonas campestris*	Broth	23-25	165	24
48		Glucose broth	25	74	16

/2/ Generation time: the average interval between cell divisions. /3/ Human strain H-37.

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11. ORGANIC COMPOUNDS AFFECTING CELL DIVISION

	Substance	Organism	Tissue	Effect	Reference
	(A)	(B)	(C)	(D)	(E)
			Interphase		
1	Acridines	*Gallus domesticus*	Chicken fibroblast	Initiation of prophase inhibited	37
2	Auxin	Spermatophyta	Flowering-plant cambium	Shortened	58
3	Azaguanine	*Mus* sp.	Mouse tumor	Initiation of prophase inhibited	66
4	Cortisone	*Allium cepa*	Onion root	Differentiated cell nuclei induced to divide	19
5	Dyes	*Rana* sp.	Frog sperm	Initiation of prophase inhibited	5
6	Folic acid antagonists	*Mus* sp.	Mouse intestine	Pycnosis from preprophase damage	23,24
7	Glucose	*Mus* sp.	Mouse epidermis	Shortened	8
8	Hydroquinone	*Mus* sp.	Mouse intestine	Pycnosis from preprophase damage	23,24
9	Hypoxanthine	*Gallus domesticus*	Chicken osteoblast	Shortened	31
10	Indoleacetic acid	*Allium cepa*	Onion root	Differentiated cell nuclei induced to divide	19
11		*Nicotiana tabacum*	Tobacco pith	Chromosome doubling within nucleus	43
12	Naphthaleneacetic acid	*Phaseolus* sp.	Bean internodes	Differentiated cell nuclei induced to divide	19
13	Neotetrazolium	*Allium cepa*	Onion root	Pycnosis from preprophase damage	56
14	Nitrogen mustard	*Rattus* sp.	Rat corneal epithelium	Initiation of prophase inhibited	26
15	Phenylacetic acid	*Allium cepa*	Onion root	Initiation of prophase inhibited	15
16	Trypaflavine	*Allium cepa*	Onion root	Destruction of interphase nucleus	52
17	Urethan	*Mus* sp.	Mouse intestine	Pycnosis from preprophase damage	23,24
			Prophase		
18	Acridines	*Allium cepa*	Onion root	Reversion to interphase	16
19	Aureomycin	*Allium cepa*	Onion root	Membrane dissolution delayed	64
20	Dichlorophenoxyacetic acid	*Allium cepa*	Onion root	Blocked	17
21	Glutathione	*Amoeba proteus*	Whole organism	Accelerated	10
22	Nitrophenols	*Arbacia punctulata*	Sea-urchin egg	Blocked	11
23	Protoanemonin	*Zea mays*	Corn root	Blocked	25
24	Purines	*Arbacia punctulata*	Sea-urchin egg	Reversion to interphase	14
25	Tropolones	*Tradescantia* sp.	Spiderwort stamen hair	Precocious chromosome split	63
26	Trypan blue	*Oryctolagus cuniculus*	Rabbit fibroblast	Spindle formation slowed	61
27	Urethan	*Oryctolagus cuniculus*	Rabbit fibroblast	Accelerated	7
			Metaphase		
28	Alcohol	*Allium cepa*	Onion root	Nucleolus neoformation	59
29	Colchicine	*Allium cepa*	Onion root	Monopolar mitotic figure induced	27
30	DDT	*Allium cepa*	Onion root	Nucleolus neoformation	59
31	Diethylbromacetyl carbamide	*Allium cepa*	Onion root	Multipolar spindle induced	49
32	Diphenyl	*Triticum* sp.	Wheat root	Spindle rotation	28
33	Endothal	*Pisum sativum*	Pea root	Chromosome noncongregation	65
34	Ethylmercuric phosphate	*Zea mays*	Corn seedling	Multipolar spindle induced	55
35	Indoleacetic acid	*Triticum* sp.	Wheat root	Spindle rotation	9
36	Methyl naphthohydroquinone diacetate	*Allium cepa*	Onion root	Multipolar spindle induced	46
37	Methyl naphthoquinone	*Allium cepa*	Onion root	Abnormal chromosome orientation	46
38	Narcotics	*Allium cepa*	Onion root	Monopolar mitotic figure induced	49
39	Phenylurethan	*Arbacia punctulata*	Sea-urchin egg	Monopolar mitotic figure induced	50
40	Streptomycin	*Allium cepa*	Onion root	Reversion to interphase	64
41	Testosterone, estrone	*Oryctolagus cuniculus*	Rabbit fibroblast	Abnormal chromosome orientation	60
42	Thallium acetate	*Allium cepa*	Onion root	Chromosome noncongregation	2
			Anaphase		
43	Caffeine	*Allium cepa*	Onion root	Incomplete chromosome separation	42
44	Ryanodine	*Echinarachnius parma*	Sand-dollar egg	Incomplete chromosome separation	13
45	Trypaflavine	*Oryctolagus cuniculus*	Rabbit fibroblast	Incomplete chromosome separation	6

continued

11. ORGANIC COMPOUNDS AFFECTING CELL DIVISION

	Substance	Organism	Tissue	Effect	Reference
	(A)	(B)	(C)	(D)	(E)
	Telophase				
46	Aureomycin	*Gallus domesticus*	Chicken fibroblast	Cytoplasmic division suppressed	33
47	Caffeine	*Allium cepa*	Onion root	Cytoplasmic division suppressed	29
48	Carbamates	*Lytechinus variegatus*	Sea-urchin egg	Cytoplasmic division suppressed	12
49		*Tripneustes esculentus*	Sea-urchin egg	Cytoplasmic division suppressed	12
50	Chloroacetophenone	*Gallus domesticus*	Chicken osteoblast	Nuclear reconstruction retarded	32
51	Nicotine	*Nicotiana tabacum*	Tobacco anther	Cytoplasmic division suppressed	35
52		*Pisum* sp.	Pea seedling	Spindle remnant persists	44
53	Quinone	*Tubifex* sp.	Oligochaete-worm egg	Cytoplasmic division suppressed	38
54	Rotenone	*Arbacia punctulata*	Sea-urchin egg	Cytoplasmic division suppressed	53
55	Sulfanilamide	*Allium cepa*	Onion root	Cytoplasmic division suppressed	4
56	Sulfhydryl compounds	Saccharomycetaceae	Yeasts	Cytoplasmic division augmented	45
57	Theobromine	*Allium cepa*	Onion root	Cytoplasmic division suppressed	29
58	Thiourea	*Gallus domesticus*	Chicken fibroblast	Nuclear reconstruction retarded	54
	Not Confined to One Phase				
59	Acenaphthene	*Allium cepa*	Onion root	Chromosome breaks; centromere misdivision	18
60	Acridines	*Allium cepa*	Onion root	Chromosome breaks; pseudochiasmata	16,18
61	Aminoacridine	*Allium cepa*	Onion root	Chromosome breaks	24
62	Aminobenzoate	*Allium cepa*	Onion root	Chromosome breaks	24
63	Ammonia	*Tradescantia* sp.	Spiderwort stamen hair	Chromosome dispersion and despiralization	62
64	Ammonium thiocyanate	*Impatiens* sp.	Snapweed pollen mother cell	Chromosome dispersion and despiralization	36
65	Antibiotics	*Allium cepa*	Onion root	Chromosome reduction induced	64
66	*n*-Butyl gallate	*Allium cepa*	Onion root	Chromosome adhesion	40
67	Coumarin	*Allium cepa*	Onion root	Chromosome breaks; pseudochiasmata	48
68	Cysteine	Protozoa	Protozoan	Chromosome reduction induced	57
69	Dyes	*Allium cepa*	Onion root	Chromosome adhesion	3
70	Epoxides	*Vicia faba*	Broad-bean root	Chromosome rearrangements	41
71	Ethoxycaffeine	*Allium cepa*	Onion root	Chromosome rearrangements	34
72	Mustards	*Allium cepa*	Onion root	Chromosome rearrangements	20
73		*Tradescantia* sp.	Spiderwort pollen mother cell	Centromere misdivision	20
74	Nucleic acid	*Allium cepa*	Onion root	Chromosome reduction induced	1
75	Phenols	*Allium cepa*	Onion root	Chromosome breaks	39
76	Sulfhydryl	*Clymenella torquata*	Bamboo-worm regenerating tissue	Chromosomes widened	30
77	Sulfoxide	*Clymenella torquata*	Bamboo-worm regenerating tissue	Chromosomes widened	30
78	Uracil	*Allium cepa*	Onion root	Chromosome breaks	22
79	Urea	*Drosophila* sp.	Fruit-fly salivary glands	Chromosome dispersion and despiralization	51
80	Urethan	*Paeonia tenuifolia*	Fernleaf-peony bud	Chromosome rearrangements	47
81		*Vicia faba*	Broad-bean root	Chromosome breaks	21

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II. REPRODUCTION

12. PROPAGATION: MAMMALS

For additional information, consult references 2 and 6. **Type of Estrus** (column E): P = polyestrous; M = monoestrous. Values in parentheses are ranges, estimate "c" or "d" unless otherwise indicated (cf. Introduction).

	Species	Common Name	Age at Puberty	Breeding Season	Estrus Type	Estrus Cycle da	Gestation Period da	Young per Litter	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
1	*Homo sapiens*	Man	♀ 13.5 (11-16)[b] yr	All year	P	28.4 (24-33)[b]	278[1] (253-303)[b]	1[2]	3,17,37, 47,50,51, 64,81
2	*Balaenoptera physalus*	Finback whale	3 yr	Nov-Mar[3], June-Aug[4]	...	....	360	1	56,67,84
3	*Bos taurus*	Cattle	6-10 mo	All year	P	(14-23)	284(210-335)	Usually 1	49,54,66
4	*Camelus bactrianus*	Bactrian camel	....	All year	P	(10-20)	(389-410)	1	8,12,65
5	*Canis familiaris*	Dog	6-8 mo	Spring-autumn	M	9	63(53-71)	7(1-22)	31,54,58
6	*Capra hircus*	Goat	8 mo	Sept-winter	P	21	151(135-160)	(1-5)	4,5
7	*Cavia porcellus*	Guinea pig	55-70 da	All year	P	(16-19)	68(58-75)	3(1-8)	11,46,83
8	*Dasypus novemcinctus*	Nine-banded armadillo	1 yr	June-Aug	...	....	(210-240)	4	75
9	*Didelphis marsupialis virginiana*	Virginia opossum	♂ 8 mo, ♀ 6 mo	Jan-Oct	P	28	(12.5-13.0)	9(5-13)	41-43
10	*Elephas maximus*	Asiatic elephant	8-16 yr	....	P	....	624(510-730)	Usually 1	18,27,28, 63,71
11	*Equus caballus*	Horse	1 yr	All year[5]	P	(10-37)	336(264-420)	Usually 1	54
12	*Erinaceus europaeus*	European hedgehog	2nd yr	Mar-Sept	M	....	(35-49)	5(3-7)	22,45
13	*Felis catus*	Cat	6-15 mo	Feb-July	P[6]	(15-28)	63(52-69)	4	9,33,35, 53,73
14	*Macaca mulatta*	Rhesus monkey	♂ 3-4 yr, ♀ 1.5-2.5 yr	All year	P	28	168(144-194)	1	1,21,44, 77-80
15	*Mesocricetus auratus*	Golden hamster	5-8 wk	All year	P	4	16(15-18)	(1-12)	15,23,70
16	*Mus musculus*	House mouse	35 da	All year	P	4	(19-31)	6(1-12)	25,62
17	*Mustela vison*	Mink	1 yr	Mar-Apr	P[6]	(8-9)	53(39-76)	(4-10)	13,29,76
18	*Myotis lucifugus*	Little brown bat	♂, 2nd summer; ♀, end 1st summer	Autumn, spring	M[7]	....	(50-60)	1	34,36,38, 59
19	*Ondatra zibethica*	Muskrat	1 yr	Apr-Oct	P	(3-5)	30(19-42)	7(1-11)	57,72
20	*Ornithorhynchus anatinus*	Platypus	1-2 yr	July-Oct	M	60	12 (incubation)	Usually 2	19,30
21	*Oryctolagus cuniculus*	European rabbit	5.5-8.5 mo	All year	P[6]	....	31(30-35)	8(1-13)	7,39,61
22	*Ovis aries*	Sheep	7-8 mo	Sept-late winter[8]	P	(14-20)	151(144-152)	(1-4)	54,66
23	*Phoca vitulina*	Harbor seal	5-6 yr	June-Aug[9], Sept[10]	M	....	270	1	26,40
24	*Phocaena phocaena*	Harbor porpoise	14 mo	July-Aug	...	....	(300-330)	1	48,60,68
25	*Procyon lotor*	Raccoon	♂ 2 yr, ♀ 1 yr	Jan-June	P	....	63(60-73)	4(1-6)	10,74
26	*Rattus norvegicus*	Norway rat	40-60 da	All year	P	(4-5)	21	(6-9)	6
27	*Sciurus carolinensis*	Gray squirrel	1-2 yr	Dec-Aug	...	....	44	4(1-6)	24,32,52
28	*Sorex araneus*	European shrew	2nd yr	Mar-Sept	P	....	(13-19)	7	14
29	*Sus scrofa*	Swine	7(5-8) mo	All year	P	(18-24)	114(101-130)	9(6-15)	49,54,55, 66,69
30	*Tamias striatus*	Eastern chipmunk	2.5-3.0 mo	Mar-July	P	....	31	(3-6)	20,38

/1/ From first day of last menses; 268(250-285)[c] days after rise in basal body temperature [82]. /2/ Multiple pregnancies (mainly twins) = 1.0-1.5% of total births [16]. /3/ Northern hemisphere. /4/ Southern hemisphere. /5/ Mainly spring-autumn. /6/ Induced ovulation. /7/ Ovulation in spring. /8/ Coarse-wooled breeds only; fine-wooled breeds, all year. [6] /9/ Atlantic. /10/ Pacific.

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continued

12. PROPAGATION: MAMMALS

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13. PROPAGATION: BIRDS

For information on additional species, consult reference 1, Part I.

Part I. NEST BUILDING, INCUBATION, AND PARENTAL CARE OF YOUNG

Symbols in columns C, D, F, G, J, and K range from 0 (no time given to specified activity) to ++++ (one sex does all the work).

	Family	Representative Genera	Nest Building ♂	Nest Building ♀	Incubation: Duration da	Incubation: Parental Activity ♂	Incubation: Parental Activity ♀	Incubation: Parental Activity Attentive Period[1]	Feeding and Care of Young: Duration[2] da	Feeding and Care of Young ♂	Feeding and Care of Young ♀	Trips[3] per Hour[4]
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
1	Anatidae (ducks, geese, swans)	*Anas, Anser, Cygnus*	+	+++	21-35	+	+++	4.0-23.7 hr	0	+	+++	....
2	Cathartidae (vultures)	*Gyps*	...	....	39-56	++	++	....	56-70	++	++	....
3	Columbidae (pigeons, doves)	*Columba, Zenaidura*	++	++	11-19	++	++	4-20 hr	10-35	++	++	0.2-1.0
4	Corvidae (crows)	*Corvus, Pica*	++	++	16-20	+	+++	35-150 min	20-38	++	++	1.7-4.0
5	Fringillidae (finches, sparrows)	*Melospiza, Passer, Serinus*	+	+++	11-14	+	+++	14.6 min to continuous	8-17	++	++	1.3-21.3
6	Laridae (gulls)	*Larus*	++	++	20-34	++	++	0.5-24.0 hr	0-several	++	++	0.2-7.0
7	Meleagridae (turkeys)	*Meleagris*	0	++++	28	0	++++	23-24 hr	0	0	++++	....
8	Phasianidae (quail, pheasant)	*Colinus, Phasianus*	++	++	21-28	+	+++	7-23+ hr	0	++	++	....
9	Spheniscidae (penguins)	*Aptenodytes*	++	++	38-56	++	++	1-5+ da	56-112	++	++	1-2/da
10	Struthionidae (ostriches)	*Struthio*	++++	0	42	+++	+	9-15 hr	0	++	++	....
11	Sturnidae (starlings)	*Sturnus*	++	++	12	++	++	20 min	20-21	++	++	19-22
12	Trochilidae (hummingbirds)	*Archilochus*	0	++++	15-17	0	++++	5-99 min	19-25	0	++++	1.1-3.3
13	Troglodytidae (wrens)	*Troglodytes*	++	++	13-19	0	++++	12-86 min	13-22	++	++	5.6-19.2
14	Turdidae (thrushes)	*Turdus*	+	+++	12-16	+	+++	12-120 min	12-18	++	++	5.5-38.5

/1/ Time parent sits on eggs at one sitting. /2/ Nestling period, time from hatching until young birds leave nest. /3/ Range of averages for various nests. /4/ Unless otherwise stated.

Contributors: (a) Kendeigh, S. Charles, (b) Skutch, Alexander F.

References: [1] Altman, P. L., and D. S. Dittmer, ed. 1962. Growth, including reproduction and morphological development. Federation of American Societies for Experimental Biology, Washington, D. C. [2] Kendeigh, S. C. 1952. Parental care and its evolution in birds. Univ. Illinois Press, Urbana. [3] Skutch, A. F. Unpublished. San Isidro del General, Costa Rica, 1961.

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13. PROPAGATION: BIRDS

Part II. CLUTCH SIZE

Requirements for selection of data: (i) at least 25 clutches recorded within less than 10 years and within a limited geographical area, (ii) proof that clutches were complete when counted, and (iii) proof that only one female laid in nest.

	Species	Common Name	Location	Clutches no.	Eggs/Clutch Mean	Eggs/Clutch Standard Deviation	Observer and Year
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
1	*Anas platyrhynchos*	Mallard duck	California	178	9.2	....	Miller, 1954
2			California	108	8.5	....	Hunt, 1955
3	*Larus argentatus*	Herring gull	New Brunswick	1,011	2.38	0.71	Paynter, 1949
4			Holland	217	2.91	0.34	Paludan, 1951
5	*Melospiza melodia*	Song sparrow	Ohio	210	4.07	0.81	Nice, 1937
6	*Perdix perdix*	European partridge	England	4,051	14.6	2.38	Lack, 19[illegible]
7	*Phasianus colchicus*	Ring-necked pheasant	Iowa	60	8.7	....	Kozicky, 1956
8			Pennsylvania	157	10.6	3.18	Randall, 1941
9	*Pica nuttalli*	Yellow-billed magpie	California	70	6.5	0.92	Linsdale, 1937
10	*Sturnus vulgaris*	Starling	Maryland	101	4.54	1.15	McAtee, 1940
11			England	105	4.85	1.08	Lack, 1948
12			Germany	95	4.44	0.99	Berndt, 1939
13			Holland	1,785	5.14	1.11	Lack, 19[illegible]8
14	*Troglodytes aedon*	House wren	Maryland	98	5.46	1.10	McAtee, 1940
15	*Turdus migratorius*	American robin	New York	127	3.39	0.62	Howell, 1942

Contributor: Davis, David E.

References: [1] Davis, D. E. 1955. In A. Wolfson, ed. Recent studies in avian biology. Univ. Illinois Press, Urbana. p. 264. [2] Davis, D. E. 1960. In H. S. Mosby, ed. Manual of game investigational techniques. Edwards Brothers, Ann Arbor, Mich. sect. 19, p. 4.

Part III. HATCHING SUCCESS: PRECOCIAL SPECIES

Only studies that recorded at least 50 nests have been included.

	Species (Common Name)	Location	Nests no.	Nests Successful %	Eggs no.	Eggs Hatched %	Observer and Year
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
1	*Anas platyrhynchos*	California	161	38.5	616	83.4	Anderson, 1957
2	(mallard duck)	California	60	52	417	49.4	Earl, 1950
3		California	209	85.2	1,622	91.4	Miller, 1954
4		Montana	....	....	1,793	71.2	Girard, 1941
5		Utah	185	59	1,582	60	Williams, 1937
6	*Colinus virginianus*	Georgia-Florida	602	36	......	....	Stoddard, 1931
7	(bobwhite quail)	Texas	189	46	......	....	Lehmann, 1946
8		Texas	59	62.9	......	....	Parmalee, 1955
9		Wisconsin	53	50.9	......	....	Errington, 1933
10	*Perdix perdix* (European	England	....	....	57,202	90.4	Lack, 1947
11	partridge)	England	7,251	78	......	....	Middleton, 1935
12		England	4,090	....	59,825	93	Middleton, 1935
13		Michigan	143	32	......	....	Yeatter, 1934
14		Washington	113	37.1	......	....	Knott, 1943
15		Wisconsin	435	32	......	....	McCabe, 1946
16	*Phasianus colchicus*	Colorado	333	65	......	....	Yeager, 1951
17	(ring-necked pheasant)	Iowa	533	25.5	1,319	83	Baskett, 1947
18		Iowa	64	....	72[illegible]	82.3	Hamerstrom, 1936
19		Michigan	193	35	......	....	English, 1946
20		Minnesota	241	28.6	......	....	Erickson, 1951
21		Ohio	563	58	......	....	Leedy, 1945
22		Ohio	358	72	......	....	Strode, 1946
23		Ontario	230	32.1	777	73.5	Ball, 1952

continued

Part III. HATCHING SUCCESS: PRECOCIAL SPECIES

	Species (Common Name)	Location	Nests no.	Nests Successful %	Eggs no.	Eggs Hatched %	Observer and Year
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
24	*Phasianus colchicus*	Oregon	145	44.8	......	....	Eklund, 1942
25	(ring-necked pheasant)	Pennsylvania	310	20.3	......	....	Randall, 1940
26		Utah	149	36	......	....	Rasmussen, 1945
27		Washington	63	27	......	....	Buss, 1950
28		Wisconsin	126	71.3	1,000	78.9	Errington, 1937

Contributors: (a) Davis, David E., (b) Nice, Margaret Morse

References: [1] Davis, D. E. 1960. In H. S. Mosby, ed. Manual of game investigational techniques. Edwards Brothers, Ann Arbor, Mich. sect. 19, p. 1. [2] Hickey, J. J. 1955. In A. Wolfson, ed. Recent studies in avian biology. Univ. Illinois Press, Urbana. p. 326.

Part IV. HATCHING AND FLEDGING SUCCESS: ALTRICIAL SPECIES

For additional information, consult reference 10.

	Species (Common Name)	Years Observed	Nests no.	Eggs no.	Hatched no.	Hatched %	Fledged no.	Fledged %	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
	Hole-Nesting Species								
1	*Passer domesticus* (house sparrow)	6	....	114	....	....	97	78.5	6
2	*Sturnus vulgaris*	...	....	10,557	....	....	7,923	75.1	5
3	(starling)	6	....	472	....	....	410	84.5	6
4	*Troglodytes aedon*	19	1,[illegible]56	6,673	5,576	82.3	5,351	79.0	3
5	(house wren)	3		211	135	64.0	118	55.2	4
6		6		469	....	....	339	83.7	6
7		21	6[illegible]	333	199	59.7	161	48.3	11
	Open-Nest Species								
8	*Melospiza melodia*	...	77	585	389	66.5	243	41.5	9
9	(song sparrow)	...	30	321	147	45.8	80	24.9	
10	*Turdus migratorius*	...	78	259	157	60.6	131	54.4	2
11	(American robin)	...	86	548	316	57.8	246	44.9	12
12	*Zenaidura macroura*	...	130	500	...	....	213	42.6	8
13	(mourning dove)	...	2,043	8,018	4,379	54.6	3,734	46.6	7
14		...	142	398	310	77.8	274	68.8	1

Contributor: Nice, Margaret Morse

References: [1] Cowan, J. B. 1952. Calif. Fish Game 38:505. [2] Howell, J. C. 1942. Am. Midland Naturalist 28:529. [3] Kendeigh, S. C. 1942. J. Wildlife Management 6:19. [4] Kuerzi, R. G. 1941. Proc. Linnaean Soc. N. Y. 52-53:1. [5] Lack, D. 1948. Evolution 2:95. [6] McAtee, W. L. 1940. Auk 57:333. [7] McClure, H. E. 1946. Ibid. 63:24. [8] Nice, M. M. 1931. Univ. Oklahoma Biol. Survey 3(1):99. [9] Nice, M. M. 1937. Trans. Linnaean Soc. N. Y. 4:143. [10] Nice, M. M. 1957. Auk 74:305. [11] Walkinshaw, L. H. 1941. Wilson Bull. 53:1. [12] Young, H. 1955. Am. Midland Naturalist 53:329.

14. PROPAGATION: REPTILES

For information on additional species, consult reference 1. The manner of fertilization for all reptiles is internal (by copulation). **Gestation Time** (column E) = period from copulation to parturition (ovoviviparous reptiles); **Incubation Time** = period from laying to hatching of eggs (oviparous reptiles). **Manner of Birth** (column F): Ovo = ovoviviparous; O = oviparous. Values in parentheses are ranges, estimate "c" or "d" (cf. Introduction).

	Species	Common Name	Age at Sexual Maturity[1] yr	Breeding Season[2]	Gestation or Incubation Time[3]	Manner of Birth	Brood or Clutch[4] Size[5]	Brood or Clutch[4] no./yr	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
1	*Alligator mississipiensis*	American alligator	(5-10)	Jan-Sept	(56-66) da	O	(29-88)	1	9,11
2	*Ancistrodon contortrix mokeson*	Northern U.S. copperhead	(2-4)	Apr-May	142 da	Ovo	(1-14)	1	4,5,14
3	*Anguis fragilis*	Slowworm	(3-4)	May-June	3 mo	Ovo	(7-19)	1	13,14
4	*Anolis carolinensis*	American "chameleon"	♂2, ♀1	Apr-Aug	(6-7) wk	O	(8-10)	1	6,15
5	*Caretta caretta*	Loggerhead turtle	....	Mar-July	(31-65) da	O	(120-130)	(2-3)	2
6	*Chelydra serpentina*	Snapping turtle	....	Apr-Nov	(81-90) da	O	25(8-80)	(1-2)	2
7	*Coluber constrictor*	American black snake	....	May-June	(1-2) mo	O	(15-25)	1	14
8	*Crotalus viridis*	Prairie rattlesnake	(3-4)	Apr-June	(4-5) mo	Ovo	(3-13)	0.5	8,10,17
9	*Eumeces fasciatus*	Five-lined skink	<2	May-June	(4-9) wk	O	(2-18)	1	3,15
10	*Heloderma suspectum*	Gila monster	....	....	1 mo	O	(5-13)	1	16
11	*Malaclemys terrapin*	Diamondback terrapin	(5-6)	Spring	3 mo	O	8	(1-3)	7
12	*Natrix erythrogaster*	Copper-bellied water snake	....	Apr-May	....	Ovo	(8-27)	1	14
13	*Phrynosoma cornutum*	Horned lizard	....	Apr-May	(39-47) da	O	(23-37)	1	15
14	*Pseudemys floridana peninsularis*	Peninsular turtle	....	Nov-June	5 mo	O	(12-29)	2	2
15	*Sceloporus graciosus*	Sagebrush lizard	....	Apr-May	62 da	O	(2-7)	1	15
16	*Sternotherus odoratus*	Musk turtle	♂(2-3), ♀(9-11)	Apr-Oct	(60-75) da	O	(1-5)	(1-2)	2,12
17	*Terrapene carolina*	Box turtle	(4-5)	Apr-May	88(70-114)da	O	(2-7)	1	2
18	*Thamnophis sirtalis*	Common garter snake	(2-3)	Mar-May and fall	(87-116) da	Ovo	28(6-51)	(1-2)	14

/1/ Males in some species mature before females. /2/ Varies with geographical location. /3/ Actual values expressed in days; approximations, in weeks or months. /4/ Brood = young produced at one time; clutch = eggs laid at one time. /5/ Number of eggs or young.

Contributors: (a) Altland, Paul D., (b) Fitch, Henry S., (c) Tanner, Vasco M.

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15. PROPAGATION: AMPHIBIANS

For information on additional species, consult reference 1. The rate of growth and development of amphibians is influenced by temperature, moisture, and light to a much greater degree than is the rate of growth and development of homoiotherms. Manner of development is oviparous. **Fertilization** olumn D): Ext = external; Int = internal. **Parental Care** (column G): 0 = none; ♀ = female guards or transports eggs; ♂ = male guards or transports eggs.

	Species	Common Name	Breeding Season	Fertilization	Eggs or Young per Brood	Egg Development	Parental Care	Form at Hatching	Period of Growth: Egg da	Period of Growth: Larva da	Period of Growth: Sexual Maturity	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
1	*Ambystoma maculatum*	Spotted salamander	Mar-Apr	Int[1]	Up to 250	In water	0	Larva	31-54	61-110	2 yr	3
2	*A. tigrinum*	Tiger salamander	Jan-Mar	Int[1]	23-110	In water	0	Larva	23-30	180+	1 yr	3,11
3	*Amphiuma tridactylum*	Three-toed amphiuma	Jan-May[2]; May-June[3]	Int[4]	42-131	In water	♀	Adult		2-3 yr		5
4	*Bufo americanus*	American toad	Mar-July	Ext	4,000-20,600	....	...	....	3-12	30-65	2-3 yr	4,7,11,14
5	*Cryptobranchus alleganiensis*	Hellbender	Aug-Dec	Ext	220-450	In water	♂	Larva	68-84	550-700	5-6 yr	2,3
6	*Hyla regilla*	Pacific tree frog	Jan-May	Ext	730-1,250	....	...	....	6-14	50-80	2 yr	8,12,14
7	*Necturus maculosus*	Mud puppy	Sept-Nov[2]; May-June[3]	Int[4]	18-180	In water	...	Larva	38-63	5 yr		2
8	*Pipa pipa*	Surinam toad	....	Ext	....	In water (back of ♀)	♀	Adult	......	....	......	6
9	*Rana catesbeiana*	American bullfrog	Feb-Aug	Ext	10,000-25,000	In water	0	Embryo	4-5	365-730	3-4 yr	12-14
10	*R. pipiens*	Leopard frog	Feb-Dec	Ext	3,500-6,500	In water	0	Embryo	9-20	60-80	3 yr	12-14
11	*Triturus viridescens*	Common newt	Apr-June	Int[1]	200-376	In water	0	Larva	20-35	80+	2 yr	3,11
12	*Xenopus laevis*	Clawed frog	Sept-Oct	Ext	<100-1,000	In water	0	Embryo	3	35-300	♂ ½, ♀ 2 yr	9,10

/1/ Spermatophore laid by male and picked up by female. /2/ Mating season. /3/ Time of oviposition. /4/ Spermatophore deposited by male in female cloaca.

Contributors: (a) Cagle, Fred R., (b) Blair, Albert P., (c) Tanner, Vasco M., (d) Fitch, Henry S.

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16. PROPAGATION: FISHES

For additional information, consult references 2,13,21,25,31-33,38. Spawning activities vary with species, locale, and water temperature. The number of eggs produced varies (from a few to millions) with the species. The number of eggs may also differ greatly within a single species, depending chiefly on the size of the female. **Water** (column D): F = fresh; S = salt; B = brackish; L = lacustrine; V = fluviatile; (a) = anadromous. **Fertilization** (column E): Ext = external; Int = internal. **Egg Type** (column F): D = demersal; PB = pelagic or buoyant eggs. **Development or Birth** (column G): O = oviparous; Ovo = ovoviviparous; V = viviparous. **Parental Care** (column I): 0 = none; ♂ = male guards nest or eggs; C = eggs covered by gravel or sand.

	Species	Common Name	Spawning Season	Spawning Water	Fertilization	Egg Type	Development or Birth	Eggs or Young per Spawning Period	Parental Care	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Pisces									
1	*Acipenser fulvescens*	Lake sturgeon	Spring, summer	F, V, L	Ext	D	O	182,000-1,000,000	0	11,20,24
2	*Amia calva*	Bowfin	Spring	F, V, L	Ext	D	O	23,000-64,000	♂	1,12,24
3	*Anguilla rostrata*	American freshwater eel	Winter	S	Ext	PB	O	5,000,000-20,000,000	...	6,22
4	*Carassius auratus*	Goldfish	Spring	F, L	Ext	D	O	3,000	0	24,40
5	*Clupea harengus*	Atlantic herring	Spring-autumn	S	Ext	D	O	20,000-40,000	0	6,22
6	*Coregonus clupeaformis*	North American lake whitefish	Autumn	F, V, L	Ext	D	O	10,000-75,000	0	12,14, 24,34
7	*Cyprinus carpio*	Carp	Spring, summer	F, L	Ext	D	O	500,000-2,000,000	0	18
8	*Esox lucius*	Northern pike	Spring	F, V, L	Ext	D	O	10,000-100,000	0	1,8,9,34
9	*Fundulus heteroclitus*	Mummichog	Spring, summer	F, V, B	Ext	D	O	460	0	22
10	*Gadus morhua*	Atlantic cod	Winter, spring	S	Ext	PB	O	3,000,000-9,000,000	0	6
11	*Hippocampus hudsonius*	Atlantic sea horse	....	S	Ext	...	O	150	♂	6,17,35
12	*Hippoglossus hippoglossus*	Atlantic halibut	Spring, summer	S	Ext	PB	O	2,182,773	...	6,19
13	*Ictalurus punctatus*	Channel catfish	Spring, summer	F, V	Ext	D	O	3,000-20,000	♂	20
14	*Lepisosteus osseus*	Longnose gar	Spring	F, V, L	Ext	D	O	6,200-77,156	...	23,26,34
15	*Lepomis macrochirus*	Bluegill	Spring, summer	F, V, L	Ext	D	O	4,670-61,815	♂	20
16	*Melanogrammus aeglefinus*	Haddock	Winter, spring	S	Ext	PB	O	169,000-1,839,581	0	6
17	*Micropterus salmoides*	Largemouth black bass	Spring, summer	F, V, L	Ext	D	O	2,000-26,000	♂	1,12
18	*Osmerus mordax*	American smelt	Spring	F, V	Ext	D	O	To 50,000	0	7,14,34
19	*Perca flavescens*	Yellow perch	Spring	F, V, L	Ext	D	O	10,000-40,000	0	1,20
20	*Polyodon spathula*	Paddlefish	Spring, winter	F, V	Ext	D	O	140,000	0	12,30, 36,37
21	*Pomoxis annularis*	White crappie	Spring, summer	F, V, L	Ext	D	O	2,900-14,750	♂	20
22	*Pseudopleuronectes americanus*	Winter flounder	Winter, spring	S	Ext	D	O	500,000-1,500,000	...	6
23	*Salmo salar*	Atlantic salmon	Spring	F, V (a)	Ext	D	O	7,000	C	15,29,36
24	*S. trutta*	Brown trout	Autumn, winter	F, V	Ext	D	O	200-6,000	C	20
25	*Salvelinus fontinalis*	Eastern brook trout	Autumn	F, V	Ext	D	O	200-2,500	C	20
26	*Scomber scombrus*	Atlantic mackerel	Spring, summer	S	Ext	PB	O	41,000-546,000	0	28
	Chondrichthyes									
27	*Dasyatis americana*	Southern stingray	....	S	Int	...	Ovo	3-5	0	5
28	*Raja erinacea*	Little skate	All year	S	Int	D	O	6	0	5
29	*Sphyrna zygaena*	Hammerhead shark	Summer	S	Int	...	V	29-37	0	3,4
30	*Squalus acanthias*	Atlantic spiny dogfish	All year	S	Int	...	Ovo	2-11	0	4

continued

16. PROPAGATION: FISHES

	Species	Common Name	Spawning		Fertilization	Egg Type	Development or Birth	Eggs or Young per Spawning Period	Parental Care	Reference
			Season	Water						
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
				Agnatha						
31	*Lampetra lamottei*	American brook lamprey	Spring	F, V	Ext	D	O	1,085-3,648	0	10,24,27
32	*Myxine glutinosa*	Atlantic hagfish	All year	S	....	D	O	19-30	0	4
33	*Petromyzon marinus*	Sea lamprey	Spring	F, V (a)	Ext	D	O	13,000-259,000	0	16,39,41

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17. PROPAGATION: AQUATIC INVERTEBRATES

For information on additional species, consult reference 2. Breeding habits of invertebrates may vary with changes in location, temperature, light, and, for marine forms, with changes in salinity. **Type of Sexuality** (column F): D = dioecious (unisexual); M = monoecious (bisexual or hermaphroditic). **Dimorphism** (column G): + = sexual dimorphism; - = no sexual dimorphism. Values in parentheses are ranges, estimate "c" (cf. Introduction).

	Class and Species (Common Name)	Distribution[1]	Sexual Maturity: Age at Onset	Sexual Maturity: Size[2] mm	Breeding Season	Sexuality: Type	Sexuality: Dimorphism	Eggs or Young per Brood	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
	Echinodermata[3]								
	Asteroidea								
1	*Asterias forbesi* (starfish)	Mexico to Maine (Long Island Sound)	(1-2) yr	(60-210)[4]	July-Oct	D[5]	-	Several thousand	1,9,10, 19
	Arthropoda								
	Merostomata[3]								
2	*Limulus polyphemus* (king crab)	Yucatan to Nova Scotia (Delaware Bay)	(9-11) yr	♂(178-258), ♀(243-351)[6]	May-June	D	+	3,000	29
	Crustacea[7]								
3	*Callinectes sapidus* (blue crab)	Uruguay to Nova Scotia (Chesapeake Bay)	♂♀ 13 mo	♂(135-215), ♀(134-185)	July-Aug	D	+	1,750,000	8,22
4	*Cyclops viridis* (cyclops)	U.S. and Europe (Germany)	♂(41-132), ♀(36-128) da	♀(1.5-5.0)[8]	All year	D	+	75(20-160)[9]	6,34,35
5	*Daphnia longispina* (water flea)	Asia, Europe, N. America (Florida)	♀(75-86) hr	♂ 1.2, ♀ 1.9	All year except winter	D[10]	+	28(4-35)	3,4,6, 15
6	*Homarus americanus* (American lobster)	Newfoundland to N. Carolina	(4-5) yr	♂(170-600), ♀(180-480)	July-Sept	D	+	8,500[11]	14,32
7	*Orconectes immunis* (crayfish)	Mississippi River & Great Lakes drainage (New York State)	♂♀ 15 mo	♂(40-60), ♀(44-90)	June-Oct	D	+	102(84-195)	24,26, 30
	Mollusca[3]								
	Bivalvia								
8	*Crassostrea virginica* (eastern oyster)	Texas to Canada (Delaware Bay)	1 yr	(25-50)	June-Aug	M[5]	-	(500,000-1,000,000)	16,18, 29
9	*Mercenaria mercenaria* (quahog)	Nova Scotia to Yucatan (Baja California)	(1-2) yr	(50-70)	July-Aug	M[5]	-	ca. 1,000,000	7,17
10	*Mytilus edulis* (mussel)	Worldwide	(1-2) yr	....	May-Sept	D	...	....	18
11	*Pecten irradians* (scallop)	Maine to Mexico	12 mo	78	....	M	-	....	11
	Gastropoda								
12	*Busycon canaliculatum* (whelk)	Cape Cod to Mexico	....	....	....	D	+	(360-6,240)	20,27, 28
13	*Helix pomatia* (land snail)	Europe and U.S.	(33-39) mo	....	May-July	M[12]	-	(40-200)	5,21,25, 27,28
14	*Littorina littorea* (periwinkle)	N. Atlantic to Florida	....	....	....	D	+	(1-3)	33
15	*Lymnaea stagnalis* (freshwater snail)	Worldwide (Wisconsin)	(4-14) mo	(50-60)	July-Oct	M[12]	-	6,000	23,28
	Polyplacophora								
16	*Ischnochiton magdalenensis* (chiton)	California to Mexico	2 yr	(35-36)	....	D	...	57,970	12,13, 27,28, 31

/1/ Habitat of animals to which data apply is given in parentheses. /2/ Greatest dimension. /3/ All species listed are oviparous. /4/ Size is dependent on food supply. /5/ Protandrous hermaphrodite: male organs appear first, later replaced by female organs. /6/ Prosomal width. /7/ All species listed are ovigerous. /8/ Male is smaller. /9/ In early summer. /10/ Parthenogenetic reproduction during most of season. /11/ Under present fisheries conditions, average is difficult to obtain because females are not permitted to attain maximum egg-laying age. /12/ Cross-fertilization.

continued

17. PROPAGATION: AQUATIC INVERTEBRATES

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18. PROPAGATION AND METAMORPHOSIS: INSECTS

For information on additional species, consult reference 2. Duration of stages varies with season, geographical area, and climate. **Type of Metamorphosis** (column B): C = complete (having internal development of wings until pupal stage); I = incomplete (having external development of wings).

	Species (Common Name)	Type of Metamorphosis	Eggs per Female	Duration of Stage, da: Egg	Larva or Nymph	Pupa	Adult	Overwintering Stage	Generations per Season	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
1	*Aedes aegypti* (yellow-fever mosquito)	C	....	2-365	6	2-3	15-60	All stages[1]	....	37
2	*Apanteles militaris* (parasitic wasp)	C	Hundreds	5-6	10-12	8-10	15-20	Larva in host body	Several	41
3	*Apis mellifera* (honeybee)	C	....	3[2]	8[2]	9[2]	35-40[2]	Adult	*See* Fn. 3	16,39
4	*Bombyx mori* (silkworm)	C	300-400	9-12	21-25	14-21	2-3	....	1-2	3,25,29
5	*Cochliomyia hominivorax* (screw-worm)	C	100-300	1-2	4-5	5-40	5-30	None	2-12	11
6	*Ctenocephalides felis* (cat flea)	C	200-400	2-4	8-24	5-7	50-200	Pupa	ca. 10	43
7	*Drosophila melanogaster* (fruit fly)	C	100	<1	3-11	2-8	14	Larva, adult	5-6	33

/1/ Insect breeds all year regardless of season. /2/ Worker bees only. /3/ Not applicable to individual bee since colony is functioning unit. Queen reproduces and can survive for several years; workers do not reproduce.

continued

18. PROPAGATION AND METAMORPHOSIS: INSECTS

	Species (Common Name)	Type of Metamorphosis	Eggs per Female	Duration of Stage, da				Overwintering Stage	Generations per Season	Reference
				Egg	Larva or Nymph	Pupa	Adult			
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
8	*Ephestia kuehniella* (Mediterranean flour moth)	C	116-700	>3	40	5-7	3-4	....	>6	24
9	*Heliothis armigera* (corn earworm)	C	1,000	2-8	13-28	14	12	Pupa	1-7	4,10,22,29, 31,32,34
10	*Leptinotarsa decemlineata* (Colorado potato beetle)	C	>500	4-9	10-21	5-10	....	Adult	1-3	9,12
11	*Magicicada septendecim* (periodical cicada)	I	400-600	42-49	13 or 17 yr	.....	30-40	Nymph	*See* Fn. 4	18,29,42
12	*Melanoplus mexicanus* (migratory grasshopper)	I	300-400	90-120	40-60	.....	>30	Egg	1	4,29,30
13	*Musca domestica* (housefly)	C	75-200	1-3	4-10	4-18	10-50	All stages[1]	4-18	5,7,13,20,21, 23,27,28,44
14	*Pediculus* sp. (louse)	I	50-300	5-21	7-10	None	10-30	All stages[1]	10-12	8,19
15	*Periplaneta americana* (American cockroach)	I	200-1,000	32-58	200-550	.....	371-441	All stages[1]	1 or less	14,26,29
16	*Pieris rapae* (imported cabbageworm)	C	200-500	7	14	7-14	....	Pupa	3-6	45
17	*Popillia japonica* (Japanese beetle)	C	40-60	14	275-300	8-20	30-45	Larva	1	6,17,29,36
18	*Stagmomantis carolina* (Carolina mantis)	I	75-300	210-300	45-75	.....	20-60	Egg	1	35
19	*Tenebrio molitor* (yellow mealworm)	C	276	12-16	>600	18-20	60-90	Larva	<1	24
20	*Thermobia domestica* (firebrat)	I	....	12-13	60-120	.....	1-2.5 yr	....	2-5	1,29,40
21	*Tribolium confusum* (confused flour beetle)	C	300-400	4-14	>22	5-18	1,000	Adult	5-6	15,24,29,38

/1/ Insect breeds all year regardless of season. /4/ 13 or 17 years per generation.

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19. PROPAGATION AND DEVELOPMENT: INVERTEBRATES

Part I. METAZOA

Fertilization (column C): Ext = external fertilization of egg; Int = internal fertilization of egg. **Sex** (column F): D = dioecious; M = monoecious.

	Phylum and Class	Genus	Fertilization	Zygote	Development	Adult Sex	Adult Form	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Chordata							
1	Cephalochordata[1]	*Branchiostoma*	Ext	Free	Direct	D	Amphioxus	3
2	Thaliacea	*Salpa*	Int	Placental	Direct	M[2]	Tunicate	3
3	Ascidiacea	*Ciona*	Ext	Free-floating	Appendicularia larva	M[2]	Sea squirt	3
4	Enteropneusta	*Saccoglossus*	Ext	Free	Free larva, gradual change to adult	D	Acorn worm	6
	Echinodermata							
5	Ophiuroidea	*Ophiopholis*	Ext	Free	Dipleurula→ophiopluteus	D	Brittle star	9
6	Asteroidea	*Asterias*	Ext	Free	Dipleurula→bipinnaria→brachiolaria	D	Starfish	1
7	Echinoidea	*Arbacia*	Ext	Free	Dipleurula→echinopluteus	D	Sea urchin	1
8	Holothuroidea	*Cucumaria*	Ext	Free	Dipleurula→modified auricularia	D[3]	Sea cucumber	1
9	Crinoidea	*Antedon*	Ext	Attached to pinnules	Dipleurula→ciliated larva→stalked crinoid	D	Feather star	3
	Arthropoda							
10	Pycnogonida	*Nymphon*	Ext	Carried by male	Direct	D	Sea spider	3
11	Arachnida	*Centrurus*	Int	In female	Direct	D	Scorpion	3
12		*Ixodes*	Int	In sticky secretion	Larva (nymphlike)	D	Tick	3
13		*Pardosa*	Int	In cocoon	Direct	D	Spider	3
14	Merostomata	*Limulus*	Ext	In beach nests	Trilobite larva	D	King crab	3
15	Crustacea	*Cambarus*	Int	Fastened to swimmerets	Direct	D	Crayfish	14
16		*Eubranchipus*	Int	In shell	Metanauplius larva	D	Fairy shrimp	1
17	Insecta	*Apis*	Int	Laid in hive	Larva→pupa	D	Honeybee	3
18		*Ephemera*	Int	Laid in water	Aquatic nymph	D	Mayfly	3
19		*Melolontha*	Int	Laid in ground	Grub→pupa	D	June beetle	3
20		*Pieris*	Int	Laid on plants	Caterpillar→pupa	D	Cabbage butterfly	3
21		*Romalea*	Int	Laid in ground	Nymph stages	D	Grasshopper	11

/1/ Subphylum. /2/ Protogynous. /3/ Also reproduce asexually.

continued

19. PROPAGATION AND DEVELOPMENT: INVERTEBRATES

Part I. METAZOA

	Phylum and Class	Genus	Fertilization	Zygote	Development	Adult: Sex	Adult: Form	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Arthropoda							
22	Chilopoda	*Lithobius*	Int	Laid in ground	Direct	D	Centipede	3
23	Diplopoda	*Julus*	Int	Laid in ground	Direct	D	Millipede	3
24	Onychophora	*Peripatus*	Int	In parent	Direct	D	Peripatus	1
	Annelida							
25	Hirudinea	*Hirudo*	Int	In capsule	Direct	M[4]	Leech	1
26	Oligochaeta	*Lumbricus*	Int	In capsule	Direct	M[4]	Earthworm	1
27	Polychaeta	*Nereis*	Ext	Free	Trochophore larva	D	Clam worm	5
	Mollusca							
28	Cephalopoda	*Loligo*	Int	Encased in sticky secretion	Direct	D	Squid	3
29	Bivalvia	*Anodonta*	Int	In gills of parent	Glochidium parasitic on fish gill	M	Mussel	1
30		*Mercenaria*	Ext	Free	Trochophore larva→veliger larva→pediveliger larva	D	Quahog	4,12
31	Gastropoda	*Buccinum*	Int	In capsule	Trochophore larva→veliger larva	D	Whelk	1
32		*Helix*	Int	In ground	Direct	M[4]	Land snail	3
33	Aplacophora	*Neomenia*	Ext	Free	Trochophore larva	M	Solenogaster	11
34	Polyplacophora	*Ischnochiton*	Ext	Free	Trochophore larva	D	Chiton	3
35	Brachiopoda	*Lingula*	Ext	Free	Trochophore larva	D	Brachiopod	1
36	Phoronida	*Phoronis*	Ext or in coelom	Attached to adult tentacles	Actinotrocha larva	M	Phoronid	11
	Polyzoa							
37	Gymnolaemata	*Bugula*	Int	In body of parent	Trochophore larva	M[5]	Colony	1
38	Phylactolaemata	*Pectinatella*	Int	In body of parent	Ciliated hollow larva gemmates	M[5]	Colony	1
39	Acanthocephala	*Macracanthorhynchus*	Int	In capsule	Acanthor→acanthella in beetle larva	D	Thorny-headed worm (in swine)	7,8
	Aschelminthes							
40	Nematoda	*Ascaris*	Int	In shell	To juvenile stage in open; completion in host	D	Large roundworm (in mammals)	7,8
41	Nematomorpha	*Gordius*	Int	Laid in strings	Larva free, then invades arthropod and develops to juvenile	D	Horsehair worm	7,8
42	Rotifera	*Philodina*	None	None	Direct	P[6]	Rotifer	7,8
	Nemertina							
43	Anopla	*Cerebratulus*	Ext	Free	Coeloblastula→pilidium	D[3]	Ribbon worm	7,8
	Platyhelminthes							
44	Cestoda	*Taenia*	Int	In capsule	Oncosphere→hexacanth→cysticercus (all development in mammals)	M[5]	Tapeworm (in mammals)	13
45	Trematoda	*Fasciola*	Int	In capsule	Miracidium→sporocyst→rediae→cercariae[7]	M[4]	Liver fluke	7,8
46	Turbellaria	*Dugesia*	Int	In capsule	Direct	M[4]	Planarian	7,8
	Ctenophora							
47	Nuda	*Beroe*	Ext	Free	Cydippid larva	M	Comb jelly	7,8
	Cnidaria							
48	Anthozoa	*Metridium*	Ext	Free	Planula	D[3]	Sea anemone	3
49	Scyphozoa	*Aurelia*	Int	In folds of oral lobes	Planula→scyphistoma→ephyrae	D	Scyphomedusa	3
50	Hydrozoa	*Obelia*	Ext	Free	Planula→colony→medusa buds	D	Marine hydra	3
	Porifera							
51	Calcarea	*Scypha*	Int	In mesenchyme	Amphiblastula	M	Calcareous sponge	2

/3/ Also reproduce asexually. /4/ Cross-fertilization. /5/ Self-fertilization. /6/ Parthenogenetic female. /7/ Miracidia are free; sporocysts, rediae, and cercariae develop in snails; cercariae leave snails and are picked up by ruminant from water or grass.

continued

19. PROPAGATION AND DEVELOPMENT: INVERTEBRATES

Part I. METAZOA

	Phylum and Class	Genus	Fertilization	Zygote	Development	Adult Sex	Adult Form	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
52	Mesozoa	*Dicyema*	Int	In body	Infusoriform larva→unknown stage→nematogen→rhombogen	M	Infusorigen	10

Contributors: (a) Brown, Relis B., (b) Lochhead, John H., (c) Carriker, Melbourne R., (d) Shuster, Carl N., Jr.

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Part II. PROTOZOA

	Class and Genus	Gametocytes	Gametes	Zygote	Development	Adult Form	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Ciliata						
1	*Paramecium*	Conjugating pair	Pieces of micronuclei		Binary fission; each conjugant divides into four	Ciliate	3,4
2	*Podophrya*	Conjugating pair	Pieces of micronuclei		Budding of ciliated larva; each conjugant divides into four	Suctorian	2-4
	Sporozoa						
3	*Eimeria*	Megagametocyte, microgametocyte	One egg, many sperm	Encysted	Multiple fission; forms 4 smaller cysts, each with 2 sporozoites	Trophozoite	1,3,4
4	*Monocystis*	Megagametocyte, microgametocyte	Multiple fission into eggs and sperm	Encysted	Multiple fission into 8 sporozoites	Trophozoite	1,3,4
5	*Plasmodium*	Megagametocyte, microgametocyte	One egg, several sperm	Ookinete	Multiple fission into many sporozoites	Trophozoite	1,3,4
	Rhizopoda						
6	*Amoeba*				Binary fission	Amoeba	3,4
7	*Endamoeba*				Binary fission	Endamoeba	3,4
8	*Patellina*[1]	Meiosis and mitosis into 16 gamonts	Each gamont forms 8 gametes		Two nuclear divisions without cell division	Schizont	5
	Mastigophora						
9	*Astasia*				Binary fission	Flagellate	3,4
10	*Trypanosoma*				Binary and multiple fission	*Trypanosoma* in vertebrates; *Leishmania* in invertebrates	3,4

/1/ Foraminifer.

continued

19. PROPAGATION AND DEVELOPMENT: INVERTEBRATES

Part II. PROTOZOA

	Class and Genus	Gametocytes	Gametes	Zygote	Development	Adult Form	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Mastigophora						
11	*Volvox*	Megagametocyte, microgametocyte	Egg, sperm	Encysted	Budding, forming daughter colonies; a sphere of flagellated cells	Colony	3,4

Contributor: Brown, Relis B.

References: [1] Bullough, W. S. 1951. Practical invertebrate anatomy. Macmillan, New York. [2] Burbanck, W. D. 1950. In F. A. Brown, Jr., ed. Selected invertebrate types. J. Wiley, New York. p. 72. [3] Hyman, L. H. 1940. The invertebrates. McGraw-Hill, New York. v. 1. [4] Hyman, L. H. 1951. Ibid. v. 2, 3. [5] Le Calvez, J. 1950. Zool. Exptl. Gen. 87:211.

20. BREEDING SYSTEMS: ANGIOSPERMS

For information on additional species, consult reference 1. Species are those of economic importance. The systems listed indicate the usual breeding classification for a species; where variability exists within a species, only the predominant system (enclosed in parentheses) is given. **System** (column C): SC-S = self-compatible (predominantly self-fertilized), with no inbreeding degeneration; SC-M = self-compatible, monoecious (staminate and pistillate flowers borne on same plant), but rarely self-fertilized under conditions of open pollination; SC-O = self-compatible, intermediate (between SC-S and SC-M), with perhaps a predominance of outcrossing; SI = self-incompatible (sterile to own pollen); D = dioecious (staminate and pistillate flowers borne on separate plants). All data are from reference 2, unless otherwise indicated.

	Species	Common Name	System
	(A)	(B)	(C)
	Monocotyledoneae		
1	*Allium cepa*	Garden onion	(SC-O)[1]
2	*Asparagus officinalis*[2]	Garden asparagus	D
3	*Avena sativa*	Common oat	SC-S
4	*Hordeum vulgare*	Barley	SC-S
5	*Iris* spp.	Iris	SC-O
6	*Lilium regale*	Regal lily	(SC-O)
7	*Oryza sativa*	Rice	SC-S
8	*Phleum pratense*	Timothy	SI
9	*Phoenix dactylifera*[2]	Date palm	D
10	*Triticum* spp.	Wheat	SC-S
11	*Yucca* spp.	Yucca	SI
12	*Zea mays*	Corn	SC-M
	Dicotyledoneae		
13	*Acer* spp.	Maple	SC-O
14	*Alnus* spp.	Alder	SC-M
15	*Beta vulgaris*	Beet	SI
16	*Betula* spp.	Birch	SC-M
17	*Capsicum frutescens*	Bush red pepper	SC-O
18	*Carya* spp.	Hickory	SC-M
19	*Catalpa speciosa*	Northern catalpa	SC-O
20	*Cinchona* spp.	Cinchona	SI
21	*Citrus* spp.	Citrus	(SC-O)[1]
22	Cucurbitaceae species	Cultivated species of gourds	SC-M
23	*Daucus carota*	Carrot	SC-O
24	*Digitalis purpurea*	Common foxglove	SC-O
25	*Fagopyrum esculentum*	Buckwheat	SI[3]
26	*Fagus* spp.	Beech	SC-M
27	*Fragaria virginiana*[2]	Virginia strawberry	D[4]
28	*Fraxinus* spp.	Ash	SC-O
29	*Glycine soja*	Soybean	(SC-S)
30	*Gossypium* spp.	Cotton	SC-S
31	*Helianthus annuus*	Common sunflower	SI
32	*Ilex* spp.[2]	Holly	D
33	*Ipomoea batatas*	Sweet potato	SI
34	*Juglans* spp.	Walnut	SC-M
35	*Lactuca sativa*	Lettuce	SC-S
36	*Lycopersicon esculentum*	Tomato	SC-O
37	*Malus pumila*	Common apple	SI
38	*Medicago sativa*	Alfalfa	SI
39	*Nicotiana tabacum*	Common tobacco	SC-O
40	*Pastinaca sativa*	Parsnip	SC-O
41	*Persea americana*	American avocado	SC-O
42	*Phaseolus vulgaris*	Kidney bean	SC-S
43	*Pisum sativum*	Garden pea	SC-S
44	*Populus* spp.[2]	Poplar	D
45	*Prunus domestica*	Garden plum	(SI)
46	*P. persica*	Peach	SC-O
47	*Pyrus communis*	Pear	SI
48	*Quercus* spp.	Oak	SC-M
49	*Raphanus sativus*	Garden radish	SI
50	*Ribes* spp.	Currant	SC-O
51	*Rosa* spp.	Roses, most species	SC-O
52	*Salix* spp.[2]	Willow	D
53	*Solanum tuberosum*	Potato	SC-O
54	*Trifolium hybridum*	Alsike clover	SI
55	*Ulmus* spp.	Elm	SC-M
56	*Vicia faba*	Broad bean	SC-O
57	*Vitis vinifera*	European grape	SC-O

/1/ Some are apomictic (reproduction without fertilization). /2/ Information from reference 3. /3/ Heterostyled, i.e., stigma and stamens inserted at different levels. /4/ Cultivated forms are selected intersexes.

continued

20. BREEDING SYSTEMS: ANGIOSPERMS

Contributor: Bateman, Angus J.

References: [1] Altman, P. L., and D. S. Dittmer, ed. 1962. Growth, including reproduction and morphological development. Federation of American Societies for Experimental Biology, Washington, D. C. [2] East, E. M. 1940. Proc. Am. Phil. Soc. 82:449. [3] Yampolsky, C., and H. Yampolsky. 1922. Bibliotheca Genet. 3:1.

21. PROPAGATION METHODS: CULTIVATED PLANTS

For information on additional species, consult reference 3. The methods listed for a genus are those most widely used in cultivation, but not all species of the genus can be propagated by each method. Horticultural varieties are not propagated by seed, as the new plants from seed may vary considerably from the parent plant. When propagation by seed is employed, the seed of species having no apparent rest period may be sown in the spring, while the seed of species having a definite rest period should be artificially stratified or sown in the autumn. **Preferred Time** (column C): spr = spring; sum = summer; aut = autumn; win = winter.

	Species (Common Name)	Method	Preferred Time	Reference
	(A)	(B)	(C)	(D)
	Gymnospermae			
1	*Abies* spp. (fir)	Seed	Aut or spr	19,20,48
2		Veneer graft	Win	31,32
3	*Cupressus* spp. (cypress)	Seed	Aut or spr	32,39,48
4		Cutting[1]	Sum	32,39,48
5		Veneer graft	Sum	32,39,48
6	*Ginkgo biloba* (ginkgo)	Seed	Spr	48
7		Cutting[1]	Spr	41
8		Whip graft	Early spr	32
9		Air layer	Spr	44,45
10	*Juniperus* spp. (juniper)	Seed	Spr or aut	32,48
11		Cutting	Late win	32,48
12		Cutting[1]	Late sum	32,48
13		Veneer or side graft	Win	32,48
14		Simple layering	Spr	48
15	*Larix* spp. (larch)	Seed	Aut or spr	32,39,48
16		Whip graft	Spr	32
17	*Picea* spp. (spruce)	Seed	Aut or spr	32,39,48
18		Cutting[1]	Sum	32
19		Veneer or side graft	Aut-win	24
20	*Pinus* spp. (pine)	Seed	Aut or spr	26
21		Veneer graft	Spr	26
22		Air layering	Spr-aut	26
23	*Taxus* spp. (yew)	Seed	Aut or spr	28,32
24		Cutting[2]	Aut-win	9,32,48
25		Cutting[1]	Sum	9,32,48
26		Air layering	Aut or spr	44,45
27	*Thuja* spp. (arborvitae)	Seed	Aut or spr	4,32
28		Cutting[2]	Aut-win	32,48
29		Cutting[1]	Sum	32,48
30		Veneer or side graft	Aut-win	20
31	*Tsuga* spp. (hemlock)	Seed	Aut or spr	32,39,48
32		Cutting[1]	Sum	32
33		Air layering	Early spr	44,45
	Angiospermae (Monocotyledoneae)			
34	*Gladiolus hortulanus* (horticultural gladiolus)	Cormels	Aut-spr	15
35	*Iris germanica* (German iris)	Rhizome division	Aut	22
36	*Lilium* spp. (lily)	Seed	Aut	5
37		Scales	Sum	22
38		Stem bulbils	Sum	20
39	*Phoenix dactylifera* (date palm)	Shoots	Spr	22
	Angiospermae (Dicotyledoneae)			
40	*Acer* spp. (maple)	Seed	Aut-spr	31,32,39
41		Cutting[2]	Win	32,35
42		Shield bud	Late sum	37
43		Side graft	Win	24,32
44		Air layering	Spr	44,45
45	*Alnus* spp. (alder)	Seed	Aut	32,39
46		Whip graft	Win	32
47	*Betula* spp. (birch)	Seed	Spr or aut	21,32,39
48		Cleft graft	Early spr	17,32
49		Air layering	Spr	44,45
50	*Carya* spp. (hickory)	Veneer graft	Win-spr	30
51	*C. illinoensis* (pecan)	Patch bud	Spr	1
52	*Catalpa* spp. (catalpa)	Seed	Spr	16,39
53	*Chrysanthemum* spp. (chrysanthemum)	Cutting[3]	Yr-round	25
54		Rough division	Aut	22
55	*Citrus hybrida* (citrus)	Inverted T-bud	Spr-sum	42
56	*Cornus* spp. (dogwood)	Seed	Aut or spr	13,32,39
57		Cutting[3]	Sum-aut	17,32
58		Simple layering	Spr	32
59		Air layering	Spr	44,45
60	*Fagus* spp. (beech)	Seed	Aut or spr	32
61		Whip or cleft graft	Early spr	32
62	*Fragaria* spp. (strawberry)	Runners	Spr	12
63	*Fraxinus* spp. (ash)	Seed	Aut or spr	32,36,39
64	*Ilex* spp. (holly)	Cutting[1]	Sum	22,48
65		Shield bud	Spr	32

/1/ Semihardwood. /2/ Hardwood. /3/ Softwood

continued

21. PROPAGATION METHODS: CULTIVATED PLANTS

	Species (Common Name)	Method	Preferred Time	Reference
	(A)	(B)	(C)	(D)
	Angiospermae (Dicotyledoneae)			
66	*Ilex* spp. (holly)	Simple layering	Spr-sum	32
67		Air layering	Spr	44,45
68	*Juglans* spp. (walnut)	Veneer graft	Early spr	10
69		Patch bud	Spr-sum	10
70	*Magnolia* spp. (magnolia)	Seed	Spr or aut	2,32,39
71		Cutting[1]	Aut	32
72		Side graft	Sum	6,32
73		Air layering	Spr	44,45
74	*Malus pumila* (common apple)	Shield bud	Spr-sum	1
75	*Persea americana* (American avocado)	Patch bud	Spr	1
76		Whip graft	Win	1
77	*Populus* spp. (poplar)	Cutting[2]	Aut	32
78		Root graft	Early win	32
79		Air layering	Early spr	44,45
80	*Prunus amygdalus* (almond)	Shield bud	Sum	1
81	*P. domestica* (garden plum)	Seed	Spr	1
82		Shield bud	Spr-sum	17
83		Top graft	Win	1
84	*P. persica* (peach)	Shield bud	June-sum	17
85	*Pyrus communis* (pear)	Shield bud	Sum	14
86		Whip graft	Win	38
87	*Quercus* spp. (oak)	Seed	Aut or spr	18,32,39
88		Side graft	Early spr	32,48
89	*Rhododendron* spp. (rhododendron)	Seed	Spr	27,39,49
90		Cutting[1]	Mid-sum	7,33,49
91		Veneer graft	Win	23,32,49
92		Simple layering	Spr-sum	17,32,49
93		Air layering	Spr-sum	11
94	*Ribes sativum* (common red currant)	Cutting[2]	Aut-win	40
95		Mound layering	Sum	1
96	*Rosa* spp. (rose)	Cutting[1]	Late spr	8,32,46,47
97		Shield bud	Spr-sum	29,38,46,47
98		Air layering	Spr-sum	44,45
99	*Ulmus* spp. (elm)	Seed	Aut or spr	32,39
100		Shoots	Early spr	17,32
101		Whip graft	Aut	17,32
102	*Vitis* spp. (grape)	Cutting[2]	Win	1,43
103		Whip graft	Late win	1
104		Chip bud	Spr	34

/1/ Semihardwood. /2/ Hardwood.

Contributors: (a) Mahlstede, John P., (b) Wyman, Donald, (c) Brase, Karl D., (d) Slate, George L.

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continued

21. PROPAGATION METHODS: CULTIVATED PLANTS

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22. SEED GERMINATION: HERBACEOUS PLANTS

For information on additional species, consult reference 1.

	Species	Common Name	Substrate	Germination Temp.[1] °C	Germination Time[2] da	Special Requirements
	(A)	(B)	(C)	(D)	(E)	(F)
			Monocotyledoneae			
1	*Allium cepa*	Garden onion	Between blotters or toweling	20	6-10	None
2	*Asparagus officinalis*	Garden asparagus	Between blotters; between folded paper toweling; soil or sand	20-30	7-21	None
3	*Avena sativa*	Common oat	Between folded paper toweling; soil or sand	15	5-10	Prechill at 5° or 10°C for 5 days
4	*Hordeum vulgare*	Barley	Between folded paper toweling; soil or sand	15	4-7	Prechill at 5° or 10°C for 5 days
5	*Oryza sativa*	Rice	Between blotters: between folded paper toweling; soil or sand	20-30	5-14	None
6	*Phleum pratense*	Timothy	Closed petri dish with cotton, blotter, or filter paper; top of blotters	20-30	5-10	Light; prechill at 5° or 10°C for 5 days
7	*Poa pratensis*	Kentucky bluegrass	Closed petri dish with cotton, blotter, or filter paper	10-30	10-28	Light; 0.1% KNO_3 solution; prechill dormant seeds at 10°C for 5 days
8	*Triticum* spp.	Wheat	Between folded paper toweling; soil or sand	15	4-7	Prechill at 5° or 10° C for 5 days
9	*Zea mays*	Corn	Rolled towel; soil or sand	25	4-7	None
			Dicotyledoneae			
10	*Antirrhinum* spp.	Snapdragon	Closed petri dish with cotton, blotter, or filter paper	20-30	5-12	Light; fresh and hybrid seed may require prechilling at 3° or 5°C for 10-20 days
11	*Beta vulgaris*	Beet	Between blotters; soil or sand	20-30	3-14	Soak in water for 2 hours; rinse, blot surface dry
12	*Capsicum* spp.	Pepper	Top of blotters	20-30	6-14	Light; 0.2% KNO_3 solution
13	*Chrysanthemum maximum*	Pyrenees chrysanthemum	Top of blotters	20-30	8	Light
14	*Cucumis sativus*	Cucumber	Between folded paper toweling; soil or sand; between blotters	20-30	3-7	None
15	*Cucurbita* spp.	Gourd	Between folded paper toweling; soil or sand	20-30	4-7	Keep substrate drier than for other seeds
16	*Daucus carota*	Carrot	Between blotters	20-30	6-21	None
17	*Fagopyrum esculentum*	Buckwheat	Between blotters; between folded paper toweling	20-30	3-6	None

/1/ Ranges indicate that a daily fluctuating temperature is preferred for germination: 16 hours at the lower temperature and 8 hours at the higher temperature. /2/ Maximum germination is usually obtained during the given time limit; for hard-coated seeds an additional 5 days is recommended.

continued

22. SEED GERMINATION: HERBACEOUS PLANTS

	Species	Common Name	Substrate	Germination Temp.[1] °C	Germination Time[2] da	Special Requirements
	(A)	(B)	(C)	(D)	(E)	(F)
	Dicotyledoneae					
18	*Glycine soja*	Soybean	Rolled towel; soil or sand	20-30	5-8	None
19	*Gossypium* spp.	Cotton	Rolled towel; soil or sand	20-30	4-12	None
20	*Helianthus annuus*	Common sunflower	Between folded paper toweling; between blotters	20-30	3-7	None
21	*Lactuca sativa*	Lettuce	Closed petri dish with cotton, blotter or filter paper	20	7	Light; prechill at 10°C for 3 days, or test at 15°C
22	*Lycopersicon esculentum*	Tomato	Between blotters or toweling; closed petri dish with cotton, blotter, or filter paper	20-30	5-14	Dormant seed: light; 0.2% KNO_3 solution
23	*Medicago sativa*	Alfalfa	Between blotters; soil or sand	20	4-7	None
24	*Nicotiana tabacum*	Tobacco	Closed petri dish with cotton, blotter, or filter paper; top of blotters	20-30	7-14	Light
25	*Pastinaca sativa*	Parsnip	Between blotters	20-30	6-28	None
26	*Phaseolus vulgaris*	Kidney bean	Rolled towel; soil or sand	20-30	5-8	None
27	*Pisum sativum*	Garden pea	Rolled towel; soil or sand	20	5-8	None
28	*Raphanus sativus*	Garden radish	Between blotters	20	4-6	None
29	*Rheum rhaponticum*	Garden rhubarb	Top of blotters; top of soil	20-30	7-21	Light
30	*Solanum melongena*	Eggplant	Closed petri dish with cotton, blotter or filter paper; top of blotters	20-30	7-14	Dormant seed: light; 0.2% KNO_3 solution
31	*Trifolium hybridum*	Alsike clover	Between blotters; soil or sand	20	3-7	Dormant seed: 15°C
32	*Vicia faba*	Broad bean	Soil or sand; creped cellulose paper wadding	20	4-14	Prechill at 10°C for 3 days

/1/ Ranges indicate that a daily fluctuating temperature is preferred for germination: 16 hours at the lower temperature and 8 hours at the higher temperature. /2/ Maximum germination is usually obtained during the given time limit; for hard-coated seeds an additional 5 days is recommended.

Contributors: Justice, O. L., and Rollin, S. F.

References: [1] Altman, P. L., and D. S. Dittmer, ed. 1962. Growth, including reproduction and morphological development. Federation of American Societies for Experimental Biology, Washington, D. C. [2] Justice, O. L., et al. 1960. Proc. Assoc. Offic. Seed Analysts 49(2):21.

23. SEED GERMINATION: FOREST TREES, NORTH AMERICAN

For information on additional species, consult reference 1. **Dormancy** (column C): E = embryo; SC = seed coat. **Storage Method** (column D): D = dry; M = moist; C = in sealed containers. **Pretreatment Method** (column G): P = stratify in moist peat; S = stratify in moist sand; H_2SO_4 = soak in concentrated sulfuric acid.

	Species (Common Name)	Seed-bearing Age[1] yr	Dormancy[2]	Storage Method	Storage °C	Storage Interval[3]	Pretreatment Method	Pretreatment °C	Pretreatment Duration	Sowing to Full Germination, da: Pretreated Seed	Sowing to Full Germination, da: Untreated Seed	Germination °C[4]	Germination Field %	Germination Lab %	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)
	Gymnospermae														
1	*Abies concolor* (white fir)	40-200	E[5]	D, C	2-4	>3 yr	S	5	60-90 da	30	>100	20-30	15	34	10
2	*Cupressus arizonica* (Arizona cypress)	......	E?	D, C	5	10 yr	S	5	60 da	30	75	20-30	15	26	10

/1/ Age of most abundant production. /2/ Dormancy may be general, variable (dormant and nondormant seeds in same sample), occasional, or rare; type is general unless otherwise indicated. /3/ Without serious loss in viability. /4/ Lower limit of range is night temperature, upper limit is day temperature. /5/ Variable.

continued

23. SEED GERMINATION: FOREST TREES, NORTH AMERICAN

	Species (Common Name)	Seed-bearing Age[1] yr	Dor-man-cy[2]	Storage			Pretreatment			Sowing to Full Germination, da		Germination			Ref-er-ence
				Meth-od	°C	Inter-val[3]	Meth-od	°C	Dura-tion	Pre-treated Seed	Un-treated Seed	°C[4]	Field %	Lab %	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)
	Gymnospermae														
3	*Juniperus virginiana* (eastern red cedar)	10-175	E+SC	D, C	-7	>2 yr	H_2SO_4	....	30 min[6]	20-30	>180	10-25	30	42	2,10
4	*Larix occidentalis* (western larch)	40-100	E[5]	D, C	5	>2 yr	S	5	30 da	20-30	60	20-30	20	27	3,10
5	*Picea glauca* (white spruce)	30->100	E	M[7],C	2-5[8]	10 yr	S	5	60-90 da[9]	30-45	50-140	20-30	35	50	5,6, 8-10
6	*Pinus strobus* (eastern white pine)	15-250	E	M[10], C	0-5	>10 yr	P or S	10	30 da[11]	30-40	60-100	20-30	50	64	8-10
7	*Sequoia gigantea* (giant sequoia)	50->300	E[5]	D, C	-3 to -1	8-24 yr	None	....	......	......	40-60	15-20	15	25	9-11
8	*Taxodium distichum* (bald cypress)	....	E+SC?	D, C	5	>1 yr	P or S	5	30-60 da	30-50	60-110	20-30	8	12	10
9	*Thuja occidentalis* (northern white cedar)	20->100	E[5]	D, C	2-5	5 yr	S	0-10	30-60 da	30	50	20-30	30	46	10
10	*Tsuga canadensis* (eastern hemlock)	30->400	E[5]	D, C	2-5	4 yr	S	5	60-120 da	60	200	20-30	20	38	10
	Angiospermae (Dicotyledoneae)														
11	*Acer saccharinum* (silver maple)	35-	None	M, C	5	2 yr	None	....	......	......	20-30	25-30	18	76	10
12	*Alnus rubra* (red alder)	10-100	E?	D, C	0-5	>1 yr	S	5	30-60 da	30-40	60	20-30	14	27	9,10
13	*Betula lenta* (sweet birch)	40-	E?	D	5-7	18 mo	P or S	0-5	40-70 da	30	90	15-32	15	43	10
14	*Carya illinoensis* (pecan)	20-300	E	C[12]	5	3->5 yr	P or S	2-7	30-90 da	45-60	200-300	20-30	50	50	10
15	*Catalpa speciosa* (northern catalpa)	20-	None?	D, C	0-5	>2 yr	None	....	......	......	60	20-30	70	75	10
16	*Fagus grandifolia* (American beech)	40-100	E	D, C	1-5	>6 mo	S	5	90 da	60	150-160	20-30	40	85	10
17	*Fraxinus americana* (white ash)	20-175	E	D, C	2-5	>3 yr	P or S	5	60-90 da	40-60	>60	20-30	20	38	9,10
18	*Juglans nigra* (black walnut)	12-130	E+SC?	D, C	2-5	>1 yr	P or S	1-10	60-120 da	15-40	100-300	20-30	55	75	4,10
19	*Populus tremuloides* (quaking aspen)	20->70	None	D, C	5	>1 yr	None	....	......	......	7	20-30	50	59	9,10
20	*Prunus serotina* (black cherry)	10-180	E+SC?	C	5	>2 yr	P or S	5	90-120 da	30	>190	15-30	30	63	7,9,10
21	*Quercus alba* (white oak)	20-300	None	D,C[13]	0-2	>1 yr	None	....	......	......	30-50	20-30	66	78	10
22	*Ulmus americana* (American elm)	15-300	E[5]	D, C	5	>2 yr	S	5	60 da	15-60	90	20-30	15	63	9,10

/1/ Age of most abundant production. /2/ Dormancy may be general, variable (dormant and nondormant seeds in same sample), occasional, or rare; type is general unless otherwise indicated. /3/ Without serious loss in viability. /4/ Lower limit of range is night temperature, upper limit is day temperature. /5/ Variable. /6/ Or stratify in moist soil for 30 days at 25°C, then stratify for 90 days at 5°C. /7/ Moisture content, 5%. /8/ Or -15° to -5°C. /9/ Or soak in water for 14 days at 5°C. /10/ Moisture content, 6%. /11/ Or soak in water for 7-10 days at 5°C. /12/ Relative humidity, 90%. /13/ Relative humidity, 80-90%.

Contributor: Rudolf, Paul O.

References: [1] Altman, P. L., and D. S. Dittmer, ed. 1962. Growth, including reproduction and morphological development. Federation of American Societies for Experimental Biology, Washington, D.C. [2] Barton, L.V. 1951. Contrib. Boyce Thompson Inst. 16:387. [3] Boe, K. N. 1958. U. S. Dept. Agr. Forest Serv. Intermountain Forest

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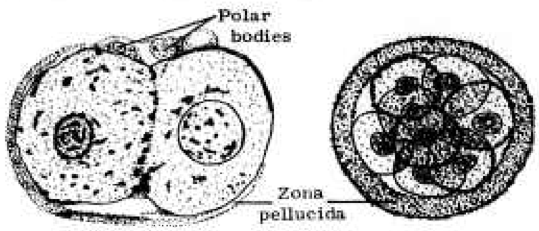
Range Expt. Sta. Misc. Publ. 16. [4] Brinkman, K. A. 1957. U. S. Dept. Agr. Forest Serv. Central States Forest Expt. Sta. Misc. Release 22. [5] Cram, W. H. 1951. Forestry Chron. 27:349. [6] Crossley, D. I., and L. Skov. 1951. Can. Dept. Resources Develop. Silvicultural Leaflet 59. [7] Hough, A. F. 1960. U. S. Dept. Agr. Forest Serv. Northeastern Forest Expt. Sta. Paper 139. [8] Rudolph, P. O. 1950. J. Forestry 48:31. [9] Rudolph, P. O. Unpublished. U. S. Dept. of Agriculture Forest Service, St. Paul, Minn., 1961. [10] Rudolph, P. O., et al. 1948. U. S. Dept. Agr. Misc. Publ. 654. [11] Schubert, G. H. 1957. U. S. Dept. Agr. Forest Serv. Calif. Forest Range Expt. Sta. Tech. Paper 20.

III. DEVELOPMENT AND GROWTH

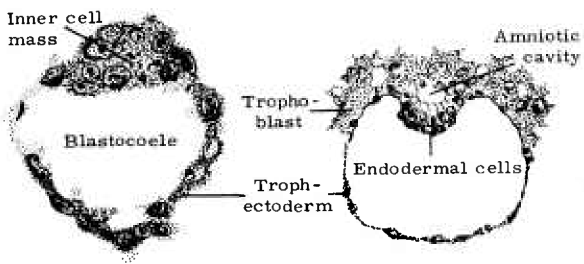
24. EARLY PRENATAL DEVELOPMENT: MAN

Diagrams show the development of germ layers and their derivatives, without regard to size relationships between stages.



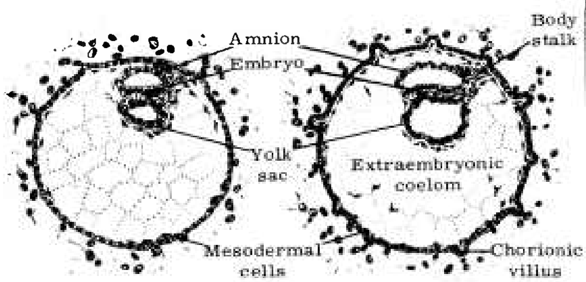
2-Cell Stage

Morula



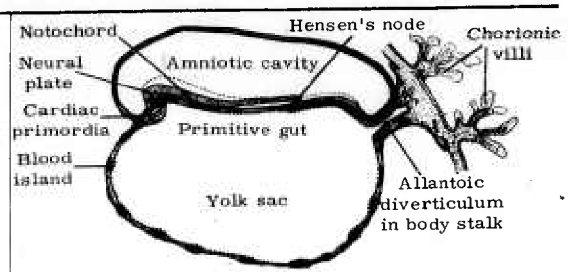
Blastodermic Vesicle

8-Day Embryo

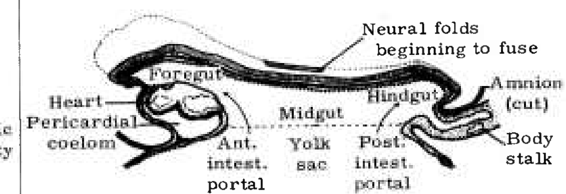


12-Day Embryo

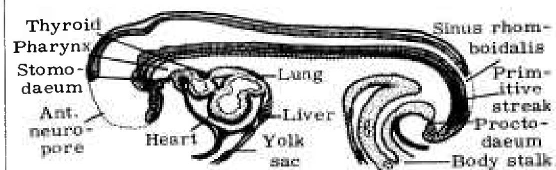
13- to 14-Day Embryo



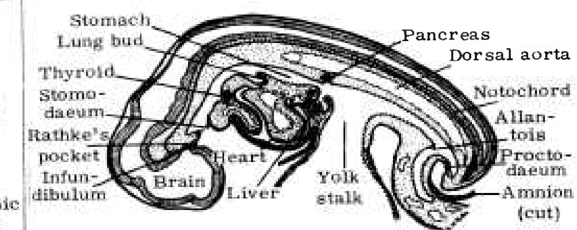
16-Day Embryo *(sagittal section)*



18-Day Embryo *(sagittal section)*



22-Day Embryo *(sagittal section)*

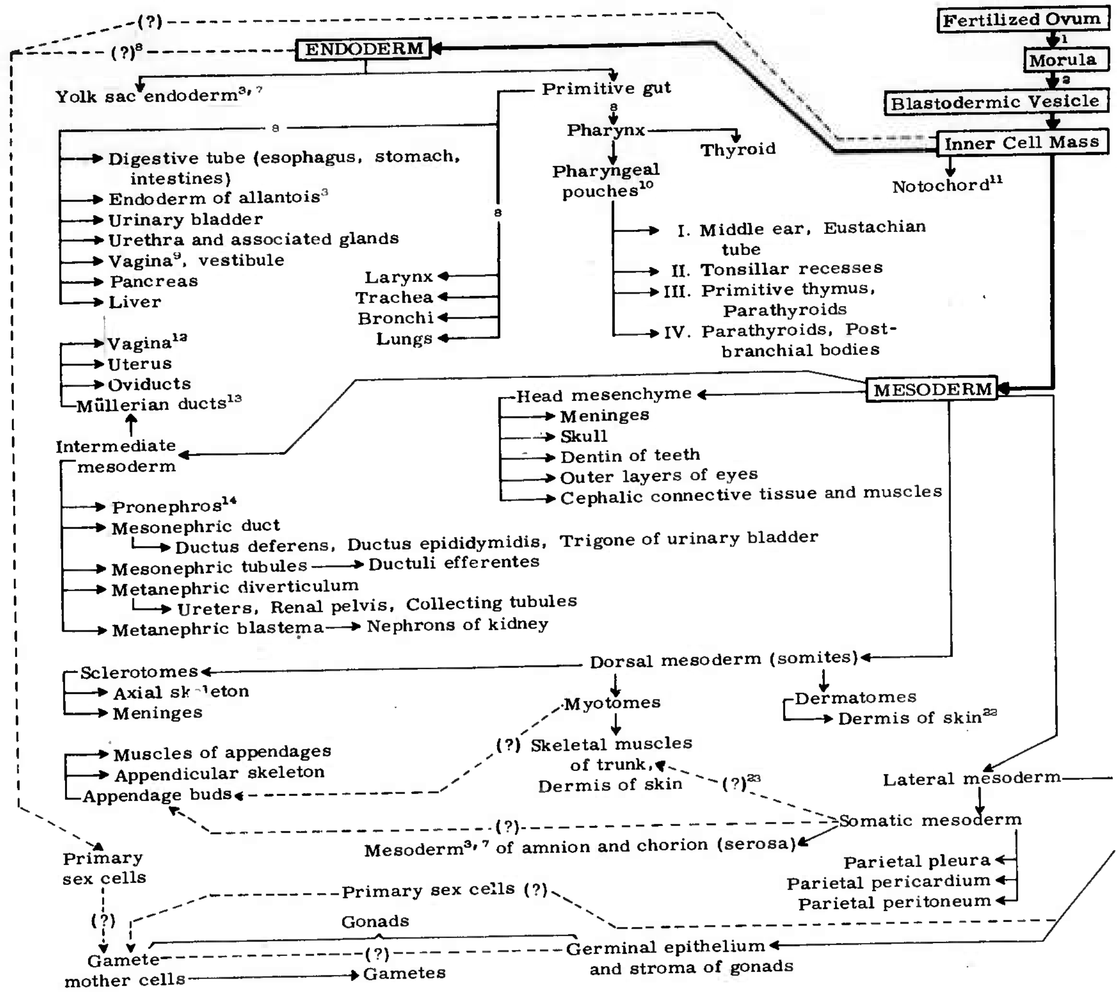


Toward End of First Month *(sagittal section)*

Contributors: (a) Hertig, Arthur T., (b) Patten, Bradley M.

References: [1] Hertig, A. T., et al. 1954. Contrib. Embryol. Carnegie Inst. Wash. 35:199. [2] Patten, B. M. 1953. Human embryology. Ed. 2. Blakiston, New York.

Adapted from B. M. Patten, *Human Embryology*, Blakiston,

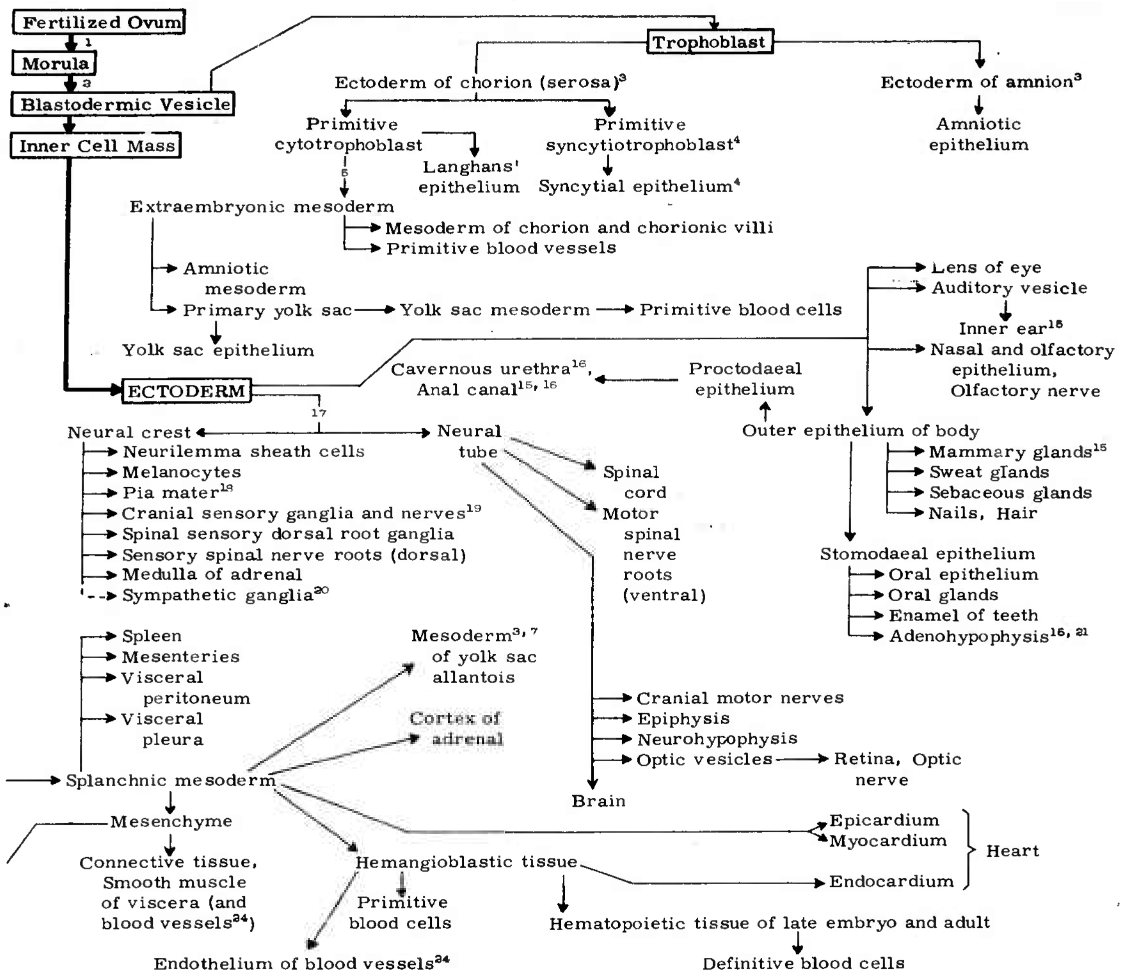


/1/ By cleavage divisions. /2/ By hollowing and expansion. /3/ Extraembryonic. /4/ Not present in all mammals. from endoderm, remainder from mesoderm. /9/ Lower part. /10/ Between visceral arches I-IV. /11/ Embryonic of peritoneum. /14/ Embryonic structure (disappears). /16/ Epithelial portion of structures from ectoderm, ectoderm along with neural crest cells. /18/ Probably in part only; remainder of pia, and all of dura and arachnoid, be derived from ectodermal placodes. /20/ Derivation from neural crest still disputed. /21/ Pars anterior, pars from chick only). /24/ Not all from splanchnic mesoderm; some from somatic mesoderm or head mesenchyme.

Contributors: (a) Patten, Bradley M., (b) Reyer, Randall W., (c) Hertig, Arthur T., (d) Arey, Leslie B.

DERIVATIVES: EUTHERIAN MAMMALS

New York, 1953. Broken line indicates disputed origin.



/5/ In primates only. /6/ In man. /7/ Probably not in primates. /8/ Epithelial and glandular portion of structure structure; may form nucleus pulposus of intervertebral discs. /12/ Upper part. /13/ Or from splanchnic mesoderm remainder from mesoderm. /16/ In part only. /17/ In rostral areas of head, some mesenchyme comes in from the from mesenchyme. /19/ Evidence from lower vertebrates indicates that a portion of these ganglia and nerves may tuberalis, and pars intermedia of hypophysis. /22/ In region of somites only. /23/ Ventral and lateral part (evidence

26. TIME VARIATIONS IN DEVELOPMENTAL STAGES: MAMMALS AND BIRDS

In mammals, hours and days were counted from time of fertilization. In birds, one day was allowed for intrauterine development and added to the incubation age (lines 4-10). Sex differentiation most often occurs at Stage 30 but varies between Stages 28 (rat) and possibly 35 (opossum).

	Standard Stages (Witschi)	Identification of Stages	Man	Hamster	Monkey, rhesus	Opossum	Rabbit	Rat	Sheep	Swine	Chick	Hawk	Sparrow
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)
1	2	2 cells	38 hr	16 hr	24 hr	40 hr	8 hr	24 hr	30 hr	30 hr	3 hr	....	......
2	3	4 cells	48 hr	40 hr	36 hr	56 hr	11 hr	48 hr	34 hr	40 hr	$3\frac{1}{4}$ hr	....	......
3	7-8	Beginning of implantation	$6\frac{1}{2}$ da	$4\frac{1}{2}$ da	9 da	6 da	7 da	6 da	10 da	.....	.....	....	......
4	12	Primitive streak	19 da	$6\frac{1}{2}$-7 da	19 da	$6\frac{1}{2}$ da	$6\frac{1}{2}$ da	$8\frac{1}{2}$ da	13 da	11 da	$1\frac{1}{2}$ da	....	$1\frac{1}{2}$ da
5	16	13-20 somite embryo	27 da	8 da	25 da	9 da	9 da	$10\frac{1}{2}$ da	17 da	16 da	3 da	$4\frac{1}{2}$ da	$2\frac{1}{2}$ da
6	18	Formation of tail bud	29 da	$8\frac{1}{2}$ da	26 da	$9\frac{1}{2}$ da	$9\frac{1}{2}$ da	$11\frac{1}{2}$ da	18 da	17 da	$3\frac{1}{4}$ da	....	$3\frac{1}{4}$ da
7	25	End of embryonic period	36 da	9 da	28 da	10 da	10 da	$12\frac{1}{2}$ da	21 da	20 da	5 da	9 da	5 da
8	33-34	End of metamorphosis	60 da	$13\frac{1}{2}$ da	40 da	12 da	14 da	$16\frac{1}{2}$ da	32 da	35 da	$8\frac{1}{2}$ da	$13\frac{1}{2}$ da	8 da
9	35	Closed eyelids	70 da	....	48 da	$12\frac{1}{4}$ da	19 da	18 da	42 da	50 da	13 da	23 da	11 da
10	36	Open eyelids	140 da	....	....	72 da[1]	42 da[2]	38 da[3]	84 da	90 da	21 da	....	20 da[4]
	Birth or hatching												
11	Age		267 da	16 da	164 da	$12\frac{1}{2}$ da	32 da	22 da	150 da	112 da	22 da	36 da	14 da
12	Standard stages (Witschi)		36	35	36	35	35+	35	36	36	36	35-36	35
13	Weight		3.2 kg	2.2 g	450 g	0.13 g	57 g	4.5 g	5 kg	2.5 kg	34 g	12 g	1.7 g
14	Weight relative to mother		5.5%	2.3%	7.5%	0.01%	3%	2.25%	8%	2.5%	3%	....	6%

/1/ 60 days after birth. /2/ 10 days after birth. /3/ 16 days after birth. /4/ 6 days after hatching.

Contributor: Witschi, Emil

Reference: Witschi, E. 1956. Development of vertebrates. W. B. Saunders, Philadelphia.

27. CHARACTERIZATION OF DEVELOPMENTAL STAGES

For information on development of tissues and organs, consult reference 1, Part I.

Part I. MAN

Age (column C) = fertilization or ovulation age, usually calculated from last menstruation minus 14 days. **Size** (column D) = greatest diameter, or crown-to-rump length (approximate chorionic size is given in parentheses). **Identification** (column E) is for standard stages, and therefore Streeter's horizons are not always comparable to the information given.

	Standard Stages (Witschi)	Streeter's Horizons	Age da	Size mm	Identification of Stages	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
					Cleavage and Blastula	
1	1	I	1	0.125	1 cell; in the tubes of the oviducts	19,24
2	2	II	2	0.115	2 cells; in the tubes of the oviducts	7,24
3	3	II		0.115	4 cells; in the tubes of the oviducts	7,24
4	4	II	3	0.100	8-12 cells (morula), entering the uterus	7
5	5	III	4	0.101	Early blastocyst (58 cells), in lumen of uterus	7
6	6	III	5	0.095	Free blastocyst (107 cells), in lumen of uterus	7
7	7	III			Blastocyst beginning of implantation	7
					Gastrula	
8	8	IV	7-8	0.05 (0.3)	Bilaminar disc (embryoblast) amniotic cavity	6,28
9	9	V	9	0.1 (0.5)	Embryonic disc and exoembryonic envelopes; exoembryonic mesoderm	6
10	10	VI	11-13	0.15 (1.0)	Beginning primitive streak; yolk sac; exocoelom	5,28
11	11	VII	14-17	0.3 (2.5)	Median primitive streak; syn- and cyto-trophoblast	11,16,28
					Primitive Streak	
12	12	VIII	19	0.7 (8.0)	Complete primitive streak; chorionic villi	15,16,28

continued

27. CHARACTERIZATION OF DEVELOPMENTAL STAGES

Part I. MAN

	Standard Stages (Witschi)	Streeter's Horizons	Age da	Size mm	Identification of Stages	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
					Neurula	
13	13	IX	20	1.5 (12.0)	Presomite neurula; spreading neural plate	9,22
14	14	X	21	2 (13)	Occipital somites 1-4; neural folds; invagination canal	10,17,23, 25
15	15	X	24	2.8 (16.0)	Cervical somites 5-12; neural tube starts forming	2,10,16, 18,21,22
16	16	XI	27	3.3 (22.0)	Thoracal somites 13-20; 2 visceral arches; upper and lower neuropores; germ cells start leaving yolk sac	8,26-28
17	17	XII	28	3.5	Thoracal somites 21-24; 3 visceral arches; oral membrane ruptures	3,14,26
					Tail-Bud Embryo	
18	18	XII	29	3.8 (24.0)	Lumbar somites 25-27; oral membrane resorbed; germ cells in hindgut and ventral mesentery	20,26,27
19	19	XII	30	4 (25)	Lumbar somites 28, 29; appendicular ridges	26,28
20	20	XIII	31	4.3 (26.0)	Sacral somites 30-32; arm and leg buds appear; germ cell migration reaches borders of mesonephric ridges	26-28
21	21	XIII	32	4.6 (27.0)	Sacral somites 33, 34; 4 visceral arches	26
22	22	XIII	33	4.8 (28.0)	Caudal somites 35, 36; otic vesicles detach	13,26
23	23	XIII	34	5 (29)	Caudal somites 37; slender yolk stalk	16,26
24	24	XIII	35	5.4 (30.0)	Caudal somites 38; lens placode; germ cells from hindgut to median mesonephric ridges	26,27
					Complete Embryo	
25	25	XIV	35-37	6 (28-35)	End of somite formation; arm and leg buds fully formed; regression of tail bud; germ cells in genital ridges, end of migration	4,12,26, 28
					Metamorphosing Embryo	
26	26	XV	38	8 (32)	Differentiation of hand plate; beginning of umbilical hernia	12,26
27	27	XVI	40	8-10 (35)	Visceral arches III and IV disappear under cervical fold and operculum; eyes pigmented; yolk sac separates from gut	26
28	28	XVII	42	12	Pentadactyl rudiments; closing of cervical sinus	26
29	29	XVII	44	12.5-14.0 (40.0)	Median processes of maxillaries advancing; chorionic villi longer where umbilicus attaches; cartilage formation in vertebrae	20,23,26, 28
30	30	XVIII	46	14.6	Premaxillary processes; beginning sexual differentiation of gonads	20,27,30
31	31	XVIII	48	15.6	Closing of facial clefts; hands and feet lateral to body wall	26,28
32	32	XIX	50	17	Phalanges, first links; hands, far apart, bending over heart; first ossification centers in mandible and clavicle	26
33	33	XX-XXII	56	22-25 (47)	Closed facial clefts; auricles rising; large umbilical hernia; arms and feet growing, fingers from left and right touch nose	26,28
					Fetus	
34	34	XXIII+	56-70	26-45	1st fetal stage: growth of eyelids; gut withdrawal from hernia; palatine raphe; differentiation of male and female external genitalia	12,16,26, 28,29
35	35		70-140	45-180	2nd fetal stage: periderm sealed eyelids; ossification of vertebral column begins; first ovocytes in ovaries; hair follicles; disc placenta	20,28,30
36	36		140-266	180-340	3rd fetal stage: resorption of periderm; cornification and separation of eyelids; lanugo; uterovaginal differentiation	20,28,29

Contributor: Witschi, Emil

References: [1] Altman, P. L., and D. S. Dittmer, ed. 1962. Growth, including reproduction and morphological development. Federation of American Societies for Experimental Biology, Washington, D. C. [2] Corner, G. W. 1929. Contrib. Embryol. Carnegie Inst. Wash. 20:81. [3] Davis, C. L. 1923. Ibid. 15:1. [4] Hamilton, W. J.,

continued

27. CHARACTERIZATION OF DEVELOPMENTAL STAGES

Part I. MAN

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Part II. RAT

Age (column B) = days after fertilization, calculated from copulation age minus 8 hours (corresponding ages of mouse embryos of the same stage, based chiefly on references 7 and 8, are given in parentheses). **Size** (column C) = largest dimension of embryo in natural position (largest and smallest dimensions of blastocysts and chorionic vesicles are given in parentheses).

	Standard Stages (Witschi)	Age da	Size mm	Identification of Stages
	(A)	(B)	(C)	(D)
				Cleavage and Blastula
1	1	1	0.07	1 cell (in oviduct)
2	2	2 (1)	0.08 x 0.06	2 cells (in oviduct)
3	3	3		4 cells (in oviduct)
4	4	3.25 (2)	0.08 x 0.05	8-12 cells (in oviduct)
5	5	3.5	0.08 x 0.04	Morula (in uterus)
6	6	4	(0.08 x 0.03)	Early blastocyst (in uterus)
7	7	5 (4)	(0.12 x 0.05)	Free blastocyst (in uterus)
				Gastrula
8	8	6 (4.5)	(0.28 x 0.07)	Implanting blastocyst, with trophoblastic cone and inner cell mass; outgrowth of endoderm (hypoblast)
9	9	6.75 (5)		Diplotrophoblast; inner cell mass (pendant), covered with endoderm
10	10	7.25 (5.5)	(0.3 x 0.1)	Near complete implantation; pendant begins differentiation into embryonic and extraembryonic parts
11	11	7.75 (6.5)	(0.5 x 0.1)	Completion of implantation; primary amniotic cyst; ectoplacental cone
				Primitive Streak
12	12	8.5 (7)	(1.04 x 0.26)	Connecting ectochorionic and amniotic cavities; rudiments of amniotic folds; primitive streak; start of 3rd layer formation; blastemas of heart and pericardium

continued

27. CHARACTERIZATION OF DEVELOPMENTAL STAGES

Part II. RAT

	Standard Stages (Witschi)	Age da	Size mm	Identification of Stages
	(A)	(B)	(C)	(D)
				Neurula
13	13	9 (7.5)	1.0 (1.40 x 0.45)	Presomite neurula; fusion of chorioamniotic folds, chorioamniotic stalk; neural plate; embryo bent dorsally; bud of allantoic stalk
14	14	9.5 (7.75)	1.5 (1.8 x 1.1)	Somites 1-4 (occipital); pendant with 3 cavities: ectochorionic cyst, exocoelom, and amniotic cavity; ectochorionic cyst collapsing; allantoic stalk projects into exocoelom; embryo bent dorsally
15	15	10 (8.0 x 8.5)	2	Somites 5-12 (cervical); 1st visceral arch; ectochorionic cyst fused with ectoplacenta and allantoic stalk; regression of peripheral (distal) yolk sac and trophectoderm (diplotrophoblast); Reichert's membrane; gonia in endoderm; embryo bent dorsally
16	16	10.5 (8.5 x 9.0)	2.4 (2.2 x 3.4)	Somites 13-20 (upper thoracic); 2 visceral arches; disc and yolk-sac placentas; appendicular folds; embryo reverses, curves ventrally
17	17	11 (9.5)	3.3	Somites 21-25 (lower thoracic); yolk stalk closes at level of 15th somite; primary gonia in mesentery; primitive streak disappears; tail bud becomes organized; arm and leg buds recognizable
				Tail-Bud Embryo
18	18	11.5 (10)	3.8	Somites 26-28 (upper lumbar); 3 visceral arches; arm buds recognizable
19	19	11.75 (10.25)	4.2	Somites 29-31 (lower lumbar); visceral arches I-IV; cervical folds; appendicular folds and buds
20	20	11.875	5 (4.7 x 5.2)	Somites 32, 33 (upper sacral)
21	21	12	5.1	Somites 34, 35 (lower sacral); deep cervical sinuses
22	22	12.125 (10.5)	5.2	Somite 36 (1st caudal); olfactory pits
23	23	12.25	5.6 (4.5 x 5.8)	Somites 37, 38 (caudal); start of umbilical herniation
	24	12.375	6	Somites 39, 40 (caudal)
				Complete Embryo
	25	12.5 (11)	6.2	Somites 41, 42 (caudal); occipital somites dispersing; 4 visceral arches; deep cervical sinuses; arm buds at somite levels 8-14, about as high as long; leg buds at somite levels 28-31, smaller; body forms a spiral of about $1\frac{1}{2}$ turns, the left face and trunk applied to yolk sac, the right side turned toward placenta; tail and allantoic stalk rise to the placenta
				Metamorphosing Embryo
26	26	12.75	7	Somites 43-45 (caudal); mandibular, maxillary, and frontonasal processes; cervical sinuses closing; mammary welts; differentiation of hand plates; arm buds vascularized, brachial nerves entering; beginning of umbilical hernia
27	27	13 (12)	8	Somites 46-48 (caudal); prominent facial processes and clefts; nose-snout projecting; cervical sinuses closed; primordia of mammary glands; round hand plates and foot plates; larger umbilical hernia
28	28	13.5 (12.5)	8.5	Somites 49-51 (caudal); 1st visceral cleft transforms into external ear duct; precartilaginous condensations in hand plates
29	29	14	9.5	Somites 52-55 (caudal); auricular hillocks on visceral arches I and II
30	30	14.5 (13)	10.5	Somites 56-60 (caudal); body uncoils; mandibular precartilage; nearly round opening of external car duct; pleuroperitoneal canal has become very narrow
31	31	15	12	Somites 61-63 (caudal); facial clefts closed; pleuroperitoneal canal closed; complete diaphragm
32	32	15.5 (14.5)	14.2 (14.3 x 8.0)	Somite 64 (caudal); pinna turns forward; maximal size of umbilical hernia
33	33	16 (15)	15.5	Somite 65 (usually this is last caudal); snout lifts off chest; last stage of metamorphosis
				Fetus
34	34	17-18 (16.0-16.5)	16-20	1st fetal stage: rapid growth of eyelids (eyes entirely covered at end of 18th day); palate complete; pinna covers ear duct; umbilical hernia withdraws

continued

27. CHARACTERIZATION OF DEVELOPMENTAL STAGES

Part II. RAT

	Standard Stages (Witschi)	Age da	Size mm	Identification of Stages
	(A)	(B)	(C)	(D)
				Fetus
35	35 ante-natal	19-22 (17-19)	20-40	2nd fetal stage: sealed eyelids; fetal membranes and placentas reach peak of development; tail grows to 10 mm; birth occurs (22nd day in rat, 19th day in mouse)
36	35 post-natal	1-16 (1-20) post-partum	40-100[1]	After birth, fetus becomes a breathing and suckling nestling[2]; during 1st 16 days (22-38 days total age), eyelids remain sealed and external ear ducts plugged with periderm
37	36 post-natal	17+ (21+) post-partum	100+[1]	Periderm seals of ears and eyelids vanish; active feeding begins within next 3 days and weaning after 1 week (total weaning age, 45-48 days for rats and mice)

/1/ Body length from nose to root of tail. During preimplantation stages, mouse development gains a lead of $1\frac{1}{2}$ to 2 days and maintains it until birth; its nestling period is correspondingly longer so that the average weaning age is nearly the same in the two species. /2/ Developmentally, nestling period belongs to second fetal stage.

Contributor: Witschi, Emil

References: [1] Butcher, E. O. 1929. Am. J. Anat. 44:381. [2] Henneberg, B. 1937. Normentafel zur Entwicklungsgeschichte der Wanderratte (*Rattus norvegicus* Erxleben). G. Fischer, Jena. [3] Huber, G. C. 1915. J. Morphol. 26:1. [4] Long, J. A., and P. L. Burlingame. 1938. Univ. Calif. (Berkeley) Publ. Zool. 43:143. [5] MacDowell, E. C., E. Allen, and C. G. MacDowell. 1927. J. Gen. Physiol. 11:57. [6] Nicholas, J. S., and D. Rudnick. 1938. J. Exptl. Zool. 78:205. [7] Otis, E. M., and R. Brent. 1954. Anat. Record 120:33. [8] Snell, G. D. 1941. The early embryology of the mouse. Blakiston, Philadelphia. pp. 1-54. [9] Witschi, E. 1956. The development of vertebrates. W. B. Saunders, Philadelphia.

Part III. SWINE

Size (column C) = greatest length, neck (spine) length, or crown-to-rump length of embryo.

	Standard Stages (Witschi)	Age da	Size mm	Identification of Stages	Reference
	(A)	(B)	(C)	(D)	(E)
				Cleavage and Blastula	
1	1		0.11-0.14	1 cell	11
2	2	1.0-1.5		2 cells	9,11
3	3	2		4 cells; passes into uterus	4,5,9,11
4	4	3		8-12 cells	4,5,9,11
5	5	3.5		16 cells (morula)	9,11
6	6	4.75		Blastocyst	6,9
7	7	5-7		Late blastocyst still free in uterus	5,11
				Gastrula	
8	8	7-8	0.49-1.36[1]	Bilaminar disc begins elongation	4,9-11
9	9	8-9	2.5-3.0[1]	Proliferation of mesoderm	4,9,11
10	10	8-9		Beginning primitive streak	9-11
11	11	10		Medium primitive streak	9,11
				Primitive Streak	
12	12	11-12	10-65[1]	Completed primitive streak; notochord; becomes attached to endometrium	5,9,11

/1/ Extraembryonic length.

continued

27. CHARACTERIZATION OF DEVELOPMENTAL STAGES

Part III. SWINE

	Standard Stages (Witschi)	Age da	Size mm	Identification of Stages	Reference
	(A)	(B)	(C)	(D)	(E)
				Neurula	
13	13	13		Presomite neurula	11
14	14	14-15	2.5-3.0	Occipital somites 1-4; 1st somite not delimited anteriorly	2,7,10, 11
15	15	15-16	3.2-5.2	Cervical somites 5-12	1,7
				Tail-Bud Embryo	
16	16	15-17	5.2-6.5	Thoracic somites 13-20; spiral torsion; heart bulge	1,7
17	17	17	4.9	Thoracic somites 21-24	1,7
18	18	16.5-18.0	4.5	Thoracic somites 25, 26; head and tail meet; anterior limb bud	1,7
19	19	16.5-17.5	3.6	Lumbar somites 27-29; hindlimb bud	1,7
20	20	17.5	6.8	Lumbar somites 30, 31; spiraling completed	1,7
21	21	17.5	5.2	Lumbar somites 32, 33; uncoiling; mandibular and maxillary processes	7
22	22	19	5.8-8.0	Sacral somites 34, 35	7
23	23	20	6.4	Sacral somites 36, 37	7
24	24	20		Caudal somites 38-40	7
				Embryo	
25	25	20	8.0-8.6	Caudal somites 41-43	7
26	26	20-21	9-10	Caudal somites 44-46; beginning of umbilical hernia	7,9
27	27	21-22	11	Caudal somites 47-49	7,9
28	28	22	11.6-14.4	Caudal somites 50-52; end of somite formation; cervical sinus closing; hand plate	3,7
29	29	22	16.4-18.6	Cervical sinus closed; lateral palatine processes; pentadactyl rudiments	7,9
30	30	28	19.4-24.0	Median (premaxillary) palatine processes; sex differentiation; eyelids and plica semilunaris	7,9
31	31	30	25	Facial clefts closing; palate developing	9
32	32	32.5	26.5-29.5	Phalanges 3 and 4 most prominent; fusion of palatine processes	3,9
33	33	34.5	35	Facial clefts closed; palate completed	7,11
				Fetus	
34	34	36-50	35-55	1st fetal stage: growth of eyelids, gut withdrawal from umbilical cord	3,8
35	35	50-90	55-130	2nd fetal stage: sealed eyelids	3,8
36	36	90-113[a]	130-280	3rd fetal stage: separation of eyelids	3,8

/a/ Duration of pregnancy is usually given as 110-116 days, with extreme deviations for certain breeds. Young are born with open eyelids and open external ear ducts.

Contributor: Kemp, Norman E.

References: [1] Boyden, E. A. 1936. A laboratory atlas of the 13-mm. pig embryo. Wistar Institute Press, Philadelphia. [2] Boyden, E. A. 1940. Contrib. Embryol. Carnegie Inst. Wash. 28:157. [3] Carey, E. J. 1922. J. Morphol. 37:1. [4] Green, W. W., and L. M. Winters. 1946. Ibid. 78:305. [5] Heuser, C. H. 1927. Contrib. Embryol. Carnegie Inst. Wash. 19:229. [6] Heuser, C. H., and G. L. Streeter. 1929. Ibid. 20:1. [7] Keibel, F. 1897. Normentafeln zur Entwicklungsgeschichte der Wirbelthiere. G. Fischer, Jena. pt. 1. [8] MacCallum, J. B. 1901. Bull. Johns Hopkins Hosp. 12:102. [9] Patten, B. M. 1948. Embryology of the pig. Ed. 3. Blakiston, New York. [10] Streeter, G. L. 1927. Contrib. Embryol. Carnegie Inst. Wash. 19:73. [11] Waterman, A. J. 1948. A laboratory manual of comparative vertebrate embryology. H. Holt, New York.

continued

27. CHARACTERIZATION OF DEVELOPMENTAL STAGES

Part IV. CHICK

Data adapted from Hamilton [2]. Times at which stages occur are approximate and are based on incubation temperature of 38°C.

	Standard Stages (Witschi)	Chick Stages[1]	Age	Identification of Stages
	(A)	(B)	(C)	(D)
				Before Laying
1	3,4	Early cleavage	3.5-4.5 hr[a]	Shell membrane of egg formed in isthmus of oviduct
2	5,6	During cleavage		Germ wall formed from marginal periblast
3	7	Late cleavage	4.5-24.0 hr[a]	Shell of egg formed in uterus
				After Laying
4	8,9	1		Preprimitive streak (embryonic shield)
5	10	2	6-7 hr	Initial primitive streak, 0.3-0.5 mm long
6	11	3	12-13 hr	Intermediate primitive streak
7	12	4	18-19 hr	Definitive primitive streak, ±1.88 mm long
8	13a	5	19-22 hr	Head process (notochord)
9	13b	6	23-25 hr	Head fold
10	14a	7	23-26 hr	1 somite; neural folds
11	14b	7 to 8-	ca. 23-26 hr	1-3 somites; coelom
12	14c	8	26-29 hr	4 somites; blood islands
13	15a	9	29-33 hr	7 somites; primary optic vesicles
14	15b	9+ to 10-	ca. 33 hr	8-9 somites; anterior amniotic fold
15	15c	10	33-38 hr	10 somites; 3 primary brain vesicles
16	16a	11	40-45 hr	13 somites; 5 neuromeres of hindbrain
17	16b	12	45-49 hr	16 somites; telencephalon
18	16c	13	48-52 hr	19 somites; atrioventricular canal
19	17a	13+ to 14-	ca. 50-52 hr	20-21 somites; tail bud
20	17b	14	50-53 hr	22 somites; trunk flexure; visceral arches I and II, clefts 1 and 2
21	17c	14+ to 15-	ca. 50-54 hr	23 somites; premandibular head cavities
22	17d	15	50-55 hr	24-27 somites; visceral arch III, cleft 3
23	18	16	51-56 hr	26-28 somites; wing bud; posterior amniotic fold
24	19	17	52-64 hr	29-32 somites; leg bud; epiphysis
25	20	18	3 da	30-36 somites extending beyond level of leg bud; allantois
26	21	19	3.0-3.5 da	37-40 somites extending into tail; maxillary process
27	22	20	3.0-3.5 da	40-43 somites; rotation completed; eye pigment
28	23	21	3.5 da	43-44 somites; visceral arch IV, cleft 4
29	24	22	3.5-4.0 da	Somites extend to tip of tail
30	25	23	4 da	Dorsal contour from hindbrain to tail is a curved line
31	26	24	4.5 da	Toe plate
32	27	25	4.5-5.0 da	Elbow and knee joints
33	28	26	5 da	1st 3 toes
34	29	27	5.0-5.5 da	Beak
35	30	28	5.5-6.0 da	3 digits, 4 toes
36	31	29	6.0-6.5 da	Rudiment of 5th toe
37	32	30	6.5-7.0 da	Feather germs; scleral papillae; egg tooth
38	33a	31	7.0-7.5 da	Web between 1st and 2nd digits
39	33b	32	7.5 da	Anterior tip of mandible has reached beak
40	34a	33	7.5-8.0 da	Web on radial margin of wing and 1st digit
41	34b	34	8 da	Nictitating membrane
42	34c	35	8.5-9.0 da	Phalanges in toes
43	34d	36	10 da	Length of 3rd toe from tip to middle of metatarsal joint = 5.4±0.3 mm; length of beak from anterior angle of nostril to tip of bill = 2.5 mm; primordium of comb; labial groove; uropygial gland
44	34e	37	11 da	Length of 3rd toe = 7.4±0.3 mm; length of beak = 3.0 mm
45	34f	38	12 da	Length of 3rd toe = 8.4±0.3 mm; length of beak = 3.1 mm
46	35a	39	13 da	Length of 3rd toe = 9.8±0.3 mm; length of beak = 3.5 mm
47	35b	40	14 da	Length of beak = 4.0 mm; length of 3rd toe = 12.7±0.5 mm
48	35c	41	15 da	Length of beak from anterior angle of nostril to tip of upper bill = 4.5 mm; length of 3rd toe = 14.9±0.8 mm
49	35d	42	16 da	Length of beak = 4.8 mm; length of 3rd toe = 16.7±0.8 mm
50	35e	43	17 da	Length of beak = 5.0 mm; length of 3rd toe = 18.6±0.8 mm

/1/ As described by Hamburger and Hamilton [1]. /a/ After ovulation.

continued

27. CHARACTERIZATION OF DEVELOPMENTAL STAGES

Part IV. CHICK

	Standard Stages (Witschi)	Chick Stages[1]	Age	Identification of Stages
	(A)	(B)	(C)	(D)
				After Laying
51	35f	44	18 da	Length of beak = 5.7 mm; length of 3rd toe = 20.4±0.8 mm
52	36a	45	19-20 da	Yolk sac half-enclosed in body cavity; chorioallantoic membrane contains less blood and is "sticky" in living embryo
53	36b	46	20-21 da	Newly hatched chick

/1/ As described by Hamburger and Hamilton [1].

Contributor: Hamilton, Howard L.

References: [1] Hamburger, V., and H. L. Hamilton. 1951. J. Morphol. 88:49. [2] Hamilton, H. L., ed. 1952. Lillie's Development of the chick. Ed. 3. H. Holt, New York.

Part V. FROG

Data are principally for *Rana pipiens*. At a given stage, age and size can be expected to vary widely with differences in geographic strains and culture conditions. **Frog Stages** (column B), designated by Arabic numerals, are for the embryo at 18°C and are adapted from Shumway [18]; those designated by Roman numerals are for the larva at 20°C and are adapted from Taylor and Kollros [22].

	Standard Stages (Witschi)	Frog Stages	Age[1]	Size mm	Identification of Stages	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
					Cleavage and Blastula	
1	0	1	0	1.5-2.0	Unfertilized egg	18
2	1	2	1 hr	1.5-2.0	Fertilized egg; gray crescent	18
3	2	3	3.5 hr		2 cells	18
4	3	4	4.5 hr		4 cells	18
5	4	5	5.7 hr		8 cells	18
6	5	6	6.5 hr		16 cells	18
7	6	7	7.5 hr		32 cells	18
8	7a	8	16 hr		Middle blastula	18
9	7b	9	21 hr		Late blastula	18
					Gastrula	
10	8	10	26 hr		Early gastrula; dorsal lip stage	18
11	9, 10	11	34 hr		Middle gastrula; blastopore C- or U-shaped	18
12	11	12	42 hr		Late gastrula; yolk plug; primitive gut	16,18
					Neurula	
13	12	13	50 hr		Early neurula; medullary plate defined	10,16,18
14	13	14	62 hr		Midneurula; well-defined neural folds approaching each other; oral plate; anal pit; postanal gut	9,18
15	14, 15	15	67 hr		Late neurula; neural folds touch each other over most of their length; neurenteric canal; embryo rotates in jelly	9,18
16	16	16	72 hr	3	Neural tube, ectoderm fused over tube; oral sucker	18,19
					Tail-Bud Embryo	
17	17	17	84 hr	3.5	Tail bud; nasal pit; dorsal aorta	10,14,18
18	18	18	96 hr	4	Muscular response to stimulation of myotome; lens placode	18,19
19	19	19	118 hr	5	Heart beats; pronephros functional; Rohon-Beard cells; thyroid evagination	12,14,15, 18
20	20	20	140 hr	6	Embryo hatched; gill circulation; lens vesicle	18,19

/1/ Comparable ages in hours at 20°C for frog stages 2 through 20: 0.5, 2.3, 3.2, 4.0, 4.8, 5.6, 7, 17, 22, 28, 30, 38, 43, 49, 52, 61, 76, 88, and 96, respectively.

continued

27. CHARACTERIZATION OF DEVELOPMENTAL STAGES

Part V. FROG

	Standard Stages (Witschi)	Frog Stages	Age	Size mm	Identification of Stages	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
					Tail-Bud Embryo	
21	21	21	162 hr	7	Mouth open; free-swimming; cornea becoming transparent; olfactory nerve; 2 rudiments of ventral pancreas; lung rudiments	14,18
22	22	22	192 hr	8	Circulation in tail fin; cartilaginous trabeculae; 2 gill slits are perforate; trabeculae carneae	14
23	23	23	216 hr	8-9	Opercular folds and labial teeth appear; spontaneous respiratory activity of mouth begins; basal plate	6,14,18
24	24	24	240 hr	9-10	Operculum closed on right side; adrenal cortex rudiment; respiratory rhythm begins	6,18,20
25	25a	25	284 hr	10-11	Operculum closed except for spiracle; rods and cones; germinal ridge; sucker regressed; rudiments of mesonephric tubules	4,16,18, 19
					Tadpole to Adult (Metamorphosis)	
26	25b	I	3 da	13	Feeding begins; rudiments of adrenal medulla and of hindlimb appear	17,22
27	25c	II	6 da	17	Lagena; neural lobe of hypophysis	1,22
28	25d	III	[illegible]	23	Limb bud of equal length and diameter; lateral motor column	3,22
29	26a	IV	19 da	33	Ovarial sac; cartilage in synotic tectum	4,14
30	26b	V	23 da	39	Limb bud twice as long as it is broad; distal half of bud is bent ventrad	22
31	26c	VI	26 da	43	Flattened paddle at distal end of limb bud; scapular cartilage; gonads distinguishable	14,22,24
32	27a	VII	31 da	50	Foot paddle indented between toes 4 and 5	22
33	27b	VIII	34 da	53	Urinary bladder rudiment; measurable thyroid hormone output	2,12,14
34	27c	IX	36 da	56	Separation of fat body from gonad; spontaneous limb twitches	14,22
35	27d	X	40 da	58	Indentations delimit toe margins; rudiments of fungiform papillae of tongue	7,22
36	28a	XI	43 da	61	Margin of 5th toe web directed toward toe 2	22
37	28b	XII	47 da	64	Margin of 5th toe web directed toward toe 1	22
38	28c	XIII	52 da	67	Margin of 5th toe web directed toward prehallux	22
39	28d	XIV	58 da	70	Rudiments of harderian glands; rudiments of skin glands	13,14
40	29a	XV	62 da	72	1st toe pads; hindlimbs take part in swimming	12,22
41	29b	XVI	64 da	73	Nictitating membrane a low fold anterior to eyeball	12
42	29c	XVII	67 da	73	Some skin glands patent; peritoneal thickening presages oviduct	4,13
43	30a	XVIII	70 da	74[a]	Cloacal tail piece resorbed; corneal reflex	11,22
44	30b	XIX	72 da	73	Tail regression begins; skin windows form	5,22
45	31	XX	74 da	70	Skin windows perforate; forelimbs emerge; oral beaks lost	5,22
46	32a	XXI	76 da	63	Upper lid forms; 1st molt	5,8
47	32b	XXII	79 da	44	Conjunctival sac complete; lateral lines regressing	8,22
48	33a	XXIII	81 da	33	Labial fringes completely lost; vasa efferentia	22,24
49	33b	XXIV	84 da	26	Tympanic membrane outlined; tail stub = 1-2 mm	22
50	33c	XXV	88 da	25[3]	Tail stub fully resorbed; oviduct extends nearly to cloaca	4,22
51	Juvenile	Juvenile	90+ da	25-70	Fully metamorphosed; gonads immature; urostyle	21,22
52	Adult	Adult	1-3 yr	60-110	Sexually mature	22

/a/ Maximum size highly variable; tadpoles over 100 mm long have been collected. /3/ Size upon completion of metamorphosis highly variable, ranging from 16 to 30 mm.

Contributor: Kollros, Jerry J.

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Part VI. SALMONID FISHES

Age (columns B-D) = days after fertilization (differences in the data of Witschi [W.], Pasteels [P.], and Lagler [L.] are due to the fact that speed of development varies widely according to temperature and other environmental factors). **Size** (column E) = length of embryo or fry (diameter of blastopore is given in parentheses). Size and Identification of Stages were compiled mostly from data in the references of Kopsch [2] and Witschi [12]. For information on development of other teleost species, consult references 1, 4, 5, 9-11.

	Standard Stages (Witschi)	Age da W.[1]	P.	L.	Size mm	Identification of Stages
	(A)	(B)	(C)	(D)	(E)	(F)
						Cleavage
1	1					1 cell, fertilized
2	2	0.5		0.5		2 cells
3	3					4 cells
4	4			1		8 cells
5	5					16-32 cells
6	6	1				Blastodisc up to 500 cells
7	7	4		5	(1.5)	Disc blastula, hypoderm largely syncytial; blastocoele
						Gastrula
8	8		3		(1.6)	Start of invagination around dorsal blastopore lip; prospective prechordal mesoblast
9	9		3.2		(1.8)	Prospective upper notochord invaginated, small gastrocoele
10	10	5	3.5		(2)	Prospective mid-notochord and first somites invaginating
11	11		3.7		0.4 (2.2)	Prospective trunk notochord and somites invaginating; primitive node forming
						Primitive Streak
12	12		4	12	0.7 (2.5)	Prospective lower notochord and median neuroblast form primitive node (axial rudiment); prospective lateral neuroblasts and left and right mesoblasts meet in germ wall (lateral folds of primitive streak)
						Neurula
13	13	10	5	12	1.0 (3.1)	Presomite neurula; lateral primitive folds start concrescing
14	14		5.5		1.5 (3.7)	1-4 somites; neural plate narrowing, forming central solid cord of blastemic brain; upper notochord distinctly differentiated; hindgut vesicle
15	15	15	6	22	2.0 (4.5)	5-9 somites; forebrain and midbrain not separated, optic rudiments protruding; hindbrain narrow, imbedded between somitic mesoderm
16	16		6	68	2.5 (4.5)	10-15 somites; optic vesicles; forebrain and midbrain with slit-shaped cavity; otic vesicles with small cavity; concrescence constantly progresses, while yolk-sac epithelia spread over surface of yolk (in teleosts with small eggs, the yolk becomes much earlier engulfed by the yolk-sac epithelia; the yolk-sac blastopore may close even before any somites have become externally noticeable)
17	17	20	6.5		3.0 (3.5)	16-25 somites; indication of lens placodes over optic vesicles; 2 or 3 visceral arches externally recognizable

/1/ Approximates natural conditions near 5°C.

continued

27. CHARACTERIZATION OF DEVELOPMENTAL STAGES

Part VI. SALMONID FISHES

	Standard Stages (Witschi)	Age da			Size mm	Identification of Stages
		W.[1]	P.	L.		
	(A)	(B)	(C)	(D)	(E)	(F)
	Tail-Bud Embryo					
18	18		7	83	3.5 (0.01)	26-30 somites; yolk-sac blastopore closes, embryo measures $\frac{1}{4}$ of entire egg circumference and is in full length attached to yolk-sac epithelium; brain cavity prolongating into upper spinal cord; flat lens placodes over optic vesicles; otic vesicles with small cavity that opens at surface; flat solid pharynx with 2 "pouches" reaching surface epithelium, 2nd one breaking through; nephrotomes in pronephric region begin to organize
19	19	30			4	31-40 somites; short, free tail bud; rhombencephalic roof becomes thin and broad; widening of ventricle
20	20			86	4.5	40-50 somites; optic vesicles start invagination; lens placodes thicken
21	21	40			5.2	50-55 somites; foregut with pharyngeal pouches; olfactory placodes thicken; deep optic cups; rudiments of plug-shaped lens; nephric blastema-nephrostomes; nephric ducts get lost in lower mesonephric blastema cords; primordial germ cells widely scattered on both sides in mesodermal blastema; hindgut vesicle
22	22	50			6	55-58 somites; 2nd and 3rd pharyngeal pouches open on surface; pectoral limb buds; olfactory placodes saucer-shaped; free lenses in eye cups; round otic vesicle develops a thick neural epithelium ventrally; acoustic ganglion. Embryo begins to separate from yolk sac, especially the forehead; liver diverticles forming; tubular midgut; anus forming; nephric tubules and corpuscles; nephric ducts with free ends left and right of rectum.
23	23	60		86	10	58-60 somites; all somites have formed; pectoral fins fairly large and differentiated; buds of pelvic fins are present but not externally noticeable; eyes now heavily pigmented; otic vesicles become labyrinths; cartilaginous skeleton of head and upper body; germ cells still free in peritoneum or mesenchyme near nephric ducts and blastema; renal corpuscles; nephric ducts unite caudal to rectum
24	24	70			15	Hatching fish (fry); pelvic fin bud below caudal end of yolk sac (about 30th somite); anus at about 40th somite; total number of somites varies normally from about 56 to 60; swim bladder has grown out from dorsal wall of esophagus; undifferentiated gonads; skin pigment appearing
	Young Adult					
25	25	80			20+	General appearance as at preceding stage, but pelvic and all unpaired fins are now well-differentiated; skin heavily pigmented; yolk sac shrinks and eventually disappears

/1/ Approximates natural conditions near 5°C.

Contributor: Witschi, Emil

References: [1] Armstrong, P. B. 1963. Stages in the development of *Ictalurus nebulosis*. Syracuse Univ. Press, Syracuse, N. Y. [2] Kopsch, F. 1898. Arch. Mikroskop. Anat. Entwicklungsmech. 51:181. [3] Lagler, K. F. 1952. Freshwater fishery biology. W. C. Brown, Dubuque, Iowa. [4] Oppenheimer, J. M. 1937. Anat. Record 68:1. [5] Outram, D. 1957. Turtox News 35:16. [6] Pasteels, J. 1936. Arch. Biol. (Leige) 47:206. [7] Schmidt, J. 1921. Compt. Rend. Trav. Lab. Carlsberg 14(15):1. [8] Schmidt, J. 1921. Ibid. ~~14(16)~~:1. [9] Solberg, A. N. 1938. Progressive Fish Culturist 40. [10] Swarup, H. 1958. J. Embryol. Exptl. Morphol. 6:373. [11] Wilson, H.V. 1889. Bull. U.S. Fisheries Comm. 9:209. [12] Witschi, E. 1956. The development of vertebrates. W. B. Saunders, Philadelphia.

28. GROWTH: MAMMALS

For information on other body measurements, consult reference 1, Part I.

Part I. BODY WEIGHT AND HEIGHT: MAN

	Subject	Date	Age yr	Males		Females		Reference
				Wt kg	Ht cm	Wt kg	Ht cm	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
1	African Pygmy	1935	Birth	3.6	45.9	3.9	47.0	4
2			1	....	71.0	7.0	65.0	
3			5	13.5	100.4	13.5	98.1	
4			7	17.6	103.9	....	102.8	
5			9	....	113.3	....	113.0	
6			11	23.0	.....	18.5	.....	
7	Argentine	1931	9	28.1	123	27.6	122	4
8			11	33.1	136	33.9	132	
9			13	40.6	147	41.9	145	
10			15	44.9	153	46.6	153	
11	Austrian	1932	1	10.3	76	9.8	75	4
12			3	14.5	95	14.0	94	
13			5	18.5	108	18.0	107	
14			7	22.5	119	22.0	118	
15			9	26.7	128	26.0	127	
16			11	31.8	137	31.5	138	
17			13	38.5	148	38.5	149	
18			15	48.0	.....	47.5	....	
19	Briton	1935	Birth	3.4	51.2	3.3	50.8	4
20			1	9.3	70.8	8.8	69.8	
21			3	13.7	96.3	13.2	96.0	
22		1926	5	15.5	108.2[1]	15.9	107.9[1]	4
23			7	19.8	118.1[1]	19.3	117.9[1]	
24			9	23.4	128.0[1]	22.0	127.8[1]	
25			11	26.8	136.7[1]	27.2	137.9[1]	
26			13	32.9	148.1[1]	32.4	149.6[1]	
27		1943	14	42.7	155.2	45.5	154.4	3
28			15	45.9	158.5	47.7	156.0	
29			16	50.9	163.8	50.0	157.5	
30			17	54.5	167.4	51.4	157.7	
31			18	56.4	168.4	51.8	158.0	
32			20	59.5	169.9	52.7	158.2	
33			22	61.8	170.9	53.2	158.5	
34	Canadian	1953	2	13.6	88.1	12.7	85.3	5
35			3	14.5	93.0	14.0	91.4	
36			4	16.8	99.6	16.3	99.6	
37			5	18.1	106.4	18.6	106.2	
38			6	20.8	113.3	19.9	112.3	
39			7	22.7	119.4	22.2	118.1	
40			8	25.8	124.7	25.8	124.2	
41			9	28.5	130.8	28.1	129.5	
42			10	31.7	135.9	31.3	135.4	
43			11	34.9	140.7	34.9	140.5	
44			12	38.1	145.8	41.7	147.8	
45			13	42.6	150.6	46.2	153.4	
46			14	48.9	158.0	48.5	155.7	
47			15	53.9	164.3	50.7	158.0	
48			16-17	61.6	169.4	54.4	158.7	
49			18-19	65.2	172.7	56.2	159.0	
50			20-24	69.8	172.5	56.2	159.5	
51	Chinese	1935	Birth	3.1	48.2	3.0	48.2	4
52			1	....	73.5	....	71.4	
53			3	....	92.0	....	89.7	
54		1927	5	14.9	104.4	14.0	108.0	
55			7	18.4	114.6	20.1	117.2	
56			9	22.2	123.7	23.4	126.6	
57			11	26.5	131.3	28.7	135.4	
58			13	32.3	141.1	37.0	145.7	
59			15	41.7	152.7	45.0	150.0	
60			17	48.3	162.4	47.5	154.3	
61			19	52.6	165.0	44.4	152.0	
62			21	53.8	166.0	49.0	156.0	
63	Czechoslovakian	1931	3	....	89.7	....	87.7	4
64			5	17.1	103.5	16.8	102.7	
65		1934	7	21.7	115.6	21.3	115.0	
66			9	26.0	125.9	25.8	124.9	
67			11	30.2	133.4	30.2	133.4	
68			13	35.5	142.9	38.0	144.7	
69		1929	15	52.1	156.0[1]	....	.....	
70			17	61.3	159.0[1]	....	.....	
71	Dane	1930	Birth	3.4	.....	3.3	.....	4
72			7	21.8	118.5	21.5	117.9	
73			9	26.2	127.9	26.2	127.5	
74			11	31.8	137.5	32.3	137.5	
75			13	38.1	146.5	40.8	148.6	
76			15	49.2	160.1	49.6	158.0	
77	Frenchman	1935	Birth	3.1	49.9	3.1	49.2	4
78			5	18.4	107.9	17.8	106.9	
79			7	22.2	117.7	21.2	116.4	
80			9	27.0	127.9	26.8	127.7	
81			11	32.6	137.8	33.9	138.6	
82	German	1928	Birth	3.5	51.0	3.3	50.5	4
83			1	9.7	75.0	9.5	74.5	
84			3	14.1	93.0	13.7	92.5	
85			5	18.6	107.0	17.8	106.5	
86			7	22.2	119.5	21.6	118.5	
87			9	26.7	129.0	25.9	128.5	
88			11	31.5	137.5	31.4	139.0	
89			13	37.5	147.0	40.2	151.0	
90			15	48.1	160.5	49.5	160.0	
91			17	59.8	170.5	56.3	164.0	
92			19	64.5	174.0	59.0	165.0	
93	Japanese	1949	Birth	3.1	50.2	3.0	49.3	8
94		1960	1	10.3	77.9	9.6	76.0	2
95			2	12.2	85.7	11.5	84.3	
96			3	14.0	93.4	13.6	92.6	
97			4	15.5	99.6	15.0	98.5	
98			5	17.1	104.7	16.5	104.0	
99			6	19.0	110.8	18.4	109.7	
100			7	21.0	116.7	20.6	115.5	
101			8	22.9	121.5	22.6	120.6	
102			9	25.6	126.6	25.1	126.0	
103			10	27.6	130.8	28.1	131.7	
104			11	30.5	135.9	32.1	138.0	
105			12	34.2	141.0	36.5	143.7	
106			13	39.1	147.6	40.7	147.9	
107			14	43.9	153.6	44.4	149.4	
108			15	49.4	158.7	47.9	151.5	
109			16	52.8	159.9	48.6	152.1	
110			17	54.9	163.2	50.1	151.8	
111			18	56.0	162.9	49.8	152.4	
112			19	55.4	163.2	50.6	152.7	
113	Roumanian	1937	5	17.5	104.5	17.0	103.7	4
114			7	21.2	115.8	20.6	115.4	
115			9	24.6	123.0	23.8	122.8	
116			11	28.7	131.2	28.7	131.6	
117			13	33.8	139.1	34.7	140.2	
118			15	39.8	146.8	41.8	148.1	
119	Russian	1935	Birth	3.4	48.6	3.3	48.6	4
120		1931	9	....	125.3	....	124.5	
121	Spaniard	1934	7	21.6	117.0	21.5	116.0	4
122			9	24.7	123.0	26.0	124.6	
123			11	29.0	132.7	31.5	134.0	
124			13	35.7	139.6	38.0	143.7	

/1/ Date of measurement, 1933.

continued

28. GROWTH: MAMMALS

Part I. BODY WEIGHT AND HEIGHT: MAN

	Subject	Date	Age yr	Males Wt kg	Males Ht cm	Females Wt kg	Females Ht cm	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
125	Swiss	1935	Birth	3.3	......	3.1	......	4
126		1933	7	22	118	19	110	
127			9	26	126	23	118	
128			11	30	136	30.5	136	
129			13	36	146	40	147	
130			15	47	157	44.5	152	
	U. S.							
131	Navaho	1936	6	20.2	116.1	19.0	113.4	4
132	Indian		7	21.7	120.8	21.2	119.0	
133			8	24.0	125.7	23.1	123.9	
134			9	26.2	131.1	25.6	129.9	
135			10	28.4	135.3	28.3	134.9	
136			11	30.4	138.9	31.2	140.2	
137			12	32.8	143.0	34.6	143.9	
138			13	36.6	149.2	39.0	150.2	
139			14	41.2	153.8	43.6	153.1	
140			15	45.3	160.5	47.7	155.3	
141			16	50.0	165.5	51.1	156.3	
142			17	54.0	167.5	52.3	157.4	
143			18	56.3	169.5	54.0	157.5	
144	Negro	1961	Birth	3.2	49.6	3.3	49.6	6
145			1	10.4	76.1	9.9	74.9	
146		1925	2	....	89.1	....	85.9	4
147			3	....	95.2	....	95.8	
148			4	....	102.0	....	100.6	
149			5	....	110.0	....	109.9	
150			6	....	116.2	....	116.2	
151			7	....	120.3	....	120.8	
152			8	....	125.8	....	124.6	
153			9	....	130.8	....	131.3	
154			10	....	135.3	....	135.2	
	U. S.							
155	Negro	1925	11	....	140.9	....	141.2	4
156			12	37.0	144.8	40.0	149.0	
157			13	43.9	150.1	43.9	153.7	
158			14	48.0	156.5	47.7	154.7	
159			15	53.0	161.0	53.0	158.1	
160			16	57.0	163.6	57.0	157.8	
161			17	....	167.0	....	158.5	
162			18	....	170.1	....	159.2	
163			19	....	172.0	....	159.9	
164	White	1934-59	Birth	3.5	50.8	3.4	50.0	7
165			1	10.5	75.4	9.5	74.4	
166			2	12.7	87.6	12.3	86.6	
167			3	14.5	96.0	14.1	95.3	
168			4	16.8	103.6	16.4	103.1	
169			5	19.1	111.0	18.6	111.3	
170			6	21.4	117.1	20.5	116.1	
171			7	24.5	122.4	22.7	121.7	
172			8	27.3	128.0	26.4	127.8	
173			9	30.0	134.1	29.1	132.3	
174			10	33.2	138.4	32.7	138.7	
175			11	37.3	144.3	37.3	145.0	
176			12	39.5	148.1	42.3	151.4	
177			13	45.0	154.2	46.4	156.0	
178			14	51.4	161.5	50.9	159.5	
179			15	58.2	168.4	53.2	161.0	
180			16	62.3	172.0	54.5	162.3	
181			17	65.0	173.5	55.5	162.8	
182			18	67.7	174.0	55.9	162.8	
183			19	69.5	174.2	56.4	162.8	
184			20-24	71.8	174.5	56.8	162.6	

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Part II. BODY WEIGHT: RODENTS

	Species	Subjects (Age)	Weight g	Reference
	(A)	(B)	(C)	(D)
	Cavia porcellus (guinea pig)[1]			
1	Inbred line	112♂ (birth)	77(55-99)	6
2	no. 2	112♂ (13 da)	127(87-167)	
3		112♂ (23 da)	165(107-223)	
4		112♂ (33 da)	192(114-270)	
5		112♂ (53 da)	266(166-366)	
	Cavia porcellus (guinea pig)[1]			
6	Inbred line	112♂ (83 da)	381(239-523)	6
7	no. 2	112♂ (113 da)	474(336-612)	
8		112♂ (143 da)	540(406-674)	
9		112♂ (173 da)	585(455-715)	
10		112♂ (233 da)	648(516-780)	

/1/ Values in parentheses (column C) are ranges, estimate "b" (cf. Introduction).

continued

28. GROWTH: MAMMALS

Part II. BODY WEIGHT: RODENTS

	Species	Subjects (Age)	Weight g	Reference
	(A)	(B)	(C)	(D)
	Cavia porcellus (guinea pig)[1]			
11	Inbred line no. 2	112♂ (293 da)	689(555-823)	6
12		112♂ (353 da)	709(581-837)	
13		112♂ (413 da)	729(597-861)	
14		112♂ (473 da)	744(612-876)	
15		112♂ (533 da)	759(631-887)	
16		112♂ (593 da)	764(642-886)	
17		112♂ (653 da)	775(647-903)	
18		112♂ (713 da)	778(656-900)	
19	Random-bred line	68♂ (birth)	94(56-132)	
20		68♂ (13 da)	168(102-232)	
21		68♂ (23 da)	227(143-311)	
22		68♂ (33 da)	268(172-364)	
23		68♂ (53 da)	345(211-479)	
24		68♂ (83 da)	456(280-632)	
25		68♂ (113 da)	571(389-753)	
26		68♂ (143 da)	658(460-856)	
27		68♂ (173 da)	719(525-913)	
28		68♂ (233 da)	813(599-1027)	
29		68♂ (293 da)	872(668-1076)	
30		68♂ (353 da)	910(686-1134)	
31		68♂ (413 da)	938(714-1162)	
32		68♂ (473 da)	952(742-1162)	
33		68♂ (533 da)	985(777-1193)	
34		68♂ (593 da)	992(774-1210)	
35		68♂ (653 da)	1001(805-1197)	
36		68♂ (713 da)	1022(780-1264)	
37	*Mesocricetus auratus* (golden hamster)[2]	111 (3 da)	3.3(2.0-5.0)	2
38		111 (7 da)	7(4-10)	
39		111 (18 da)	23(9-33)	
40		111 (25 da)	40(17-51)	
41		111 (45 da)	79(65-88)	
42		111 (90 da)	103(94-112)	
43		111 (180 da)	112(103-121)	
44		111 (730 da)	105(97-113)	
	Mus musculus (house mouse)			
45	Piebald, black predominant[2]	81♂ (birth)	1.25(0.80-1.68)	5
46		78♀ (birth)	1.26(0.89-1.68)	
47		81♂ (1 wk)	4.03(2.67-5.69)	
48		78♀ (1 wk)	4.04(2.93-5.90)	
49		81♂ (2 wk)	6.54(4.61-9.28)	
50		78♀ (2 wk)	6.52(4.74-8.65)	
51		81♂ (3 wk)	8.76(6.48-11.90)	
52		78♀ (3 wk)	8.72(6.00-11.52)	
53		81♂ (4 wk)	12.13(7.88-16.80)	
54		78♀ (4 wk)	11.94(8.46-15.50)	
55		81♂ (5 wk)	14.94(9.90-21.35)	
56		78♀ (5 wk)	14.73(9.70-17.70)	
57		81♂ (6 wk)	17.60(10.15-24.25)	
58		78♀ (6 wk)	16.77(8.75-21.20)	
59		81♂ (7 wk)	20.06(12.10-25.65)	
60		78♀ (7 wk)	18.42(11.40-21.40)	
61		81♂ (8 wk)	21.59(15.35-26.60)	
62		78♀ (8 wk)	19.81(13.90-23.15)	
63		81♂ (12 wk)	24.78(18.70-31.30)	
64		78♀ (12 wk)	22.99(16.75-27.75)	
65		81♂ (16 wk)	27.70(20.70-38.95)	
66		78♀ (16 wk)	26.11(18.77-35.20)	
67		81♂ (20 wk)	29.91(22.83-41.62)	
68		78♀ (20 wk)	29.03(20.08-42.68)	
69		81♂ (24 wk)	31.68(22.83-44.43)	
70		78♀ (24 wk)	31.41(20.50-45.35)	
	Mus musculus (house mouse)			
71	Piebald, black predominant[2]	81♂ (28 wk)	33.07(23.70-45.45)	5
72		78♀ (28 wk)	33.00(21.43-46.97)	
73		81♂ (32 wk)	34.07(22.68-46.67)	
74		78♀ (32 wk)	34.52(22.42-49.85)	
75		81♂ (36 wk)	35.49(24.53-50.93)	
76		78♀ (36 wk)	36.38(22.58-50.68)	
77	White[1]	50♂ (3 wk)	8.16(7.34-8.98)	7
78		50♂ (4 wk)	12.44(11.58-13.30)	
79		50♂ (5 wk)	17.1(16.2-18.0)	
80		50♂ (6 wk)	19.56(18.66-20.46)	
81		50♂ (7 wk)	21.06(20.00-22.12)	
82		50♂ (8 wk)	22.22(20.96-23.48)	
83		43♂ (12 wk)	25.27(24.19-26.35)	
84		42♂ (16 wk)	27.19(25.69-28.69)	
85		42♂ (20 wk)	27.81(26.39-29.23)	
86		38♂ (24 wk)	27.58(26.36-28.80)	
87		24♂ (28 wk)	28.04(26.38-29.70)	
88		22♂ (32 wk)	29.36(28.22-30.50)	
	Rattus norvegicus (Norway rat)			
89	Long-Evans, mixed	30-50♂ (birth)	6.12	3,4
90		30-50♀ (birth)	5.75	
91		30-50♂ (3 wk)	40	
92		30-50♀ (3 wk)	39	
93		30-50♂ (4 wk)	56	
94		30-50♀ (4 wk)	52	
95		30-50♂ (5 wk)	92	
96		30-50♀ (5 wk)	84	
97		30-50♂ (6 wk)	125	
98		30-50♀ (6 wk)	105	
99		30-50♂ (7 wk)	155	
100		30-50♀ (7 wk)	123	
101		30-50♂ (8 wk)	185	
102		30-50♀ (8 wk)	140	
103		30-50♂ (10 wk)	221	
104		30-50♀ (10 wk)	167	
105		30-50♂ (12 wk)	259	
106		30-50♀ (12 wk)	178	
107		30-50♂ (15 wk)	295	
108		30-50♀ (15 wk)	198	
109		30-50♂ (20 wk)	350	
110		30-50♀ (20 wk)	223	
111		30-50♂ (30 wk)	405	
112		30-50♀ (30 wk)	250	
113		30-50♂ (40 wk)	434	
114		30-50♀ (40 wk)	265	
115		30-50♂ (52 wk)	470	
116		30-50♀ (52 wk)	276	
117	Sherman, albino, small[1]	27♂ (birth)	5.5(4.9-6.1)	8
118		39♀ (birth)	5.52(4.80-6.20)	
119		27♂ (1 wk)	13.4(10.0-16.5)	
120		39♀ (1 wk)	13.1(10.5-16.0)	
121		27♂ (2 wk)	25.3(20.5-30.0)	
122		39♀ (2 wk)	24.9(20.0-30.0)	
123		27♂ (3 wk)	40.4(32.0-48.5)	
124		39♀ (3 wk)	36.8(30.5-43.0)	
125		27♂ (4 wk)	60.7(50.5-70.5)	
126		39♀ (4 wk)	55.6(48.0-63.0)	
127		27♂ (5 wk)	89.6(76.0-104.0)	
128		39♀ (5 wk)	77.5(68.0-87.0)	
129		27♂ (6 wk)	121(106-136)	
130		39♀ (6 wk)	100(89-111)	

/1/ Values in parentheses (column C) are ranges, estimate "b" (cf. Introduction). /2/ Values in parentheses (column C) are ranges, estimate "c" (cf. Introduction).

continued

28. GROWTH: MAMMALS

Part II. BODY WEIGHT: RODENTS

	Species	Subjects (Age)	Weight g	Reference
	(A)	(B)	(C)	(D)
	Rattus norvegicus (Norway rat)			
131	Sherman, albino, small[1]	27♂ (7 wk)	150(124-175)	8
132		39♀ (7 wk)	116(106-127)	
133		27♂ (8 wk)	177(149-205)	
134		39♀ (8 wk)	130(122-137)	
135		27♂ (10 wk)	222(191-254)	
136		39♀ (10 wk)	154(145-163)	
137		27♂ (12 wk)	252(213-291)	
138		39♀ (12 wk)	169(159-179)	
139		27♂ (15 wk)	285(241-329)	
140		39♀ (15 wk)	185(165-205)	
141		27♂ (20 wk)	326(278-373)	
142		39♀ (20 wk)	202(178-225)	
143		27♂ (30 wk)	376(335-417)	
144		39♀ (30 wk)	230(205-255)	
145		39♀ (40 wk)	240(215-265)	
146		39♀ (52 wk)	248(221-275)	
147	Sherman, albino, large[1]	26♂ (birth)	6.08(4.90-7.70)	8
148		38♀ (birth)	5.75(4.90-6.60)	
149		26♂ (1 wk)	17.5(12.5-22.5)	
150		38♀ (1 wk)	16.2(13.0-19.0)	
151		26♂ (2 wk)	36.9(28.5-45.0)	
152		38♀ (2 wk)	33.5(27.5-39.5)	
153		26♂ (3 wk)	59.6(48.0-71.0)	
154		38♀ (3 wk)	53(43-63)	
155		26♂ (4 wk)	92.9(78.0-108.0)	
156		38♀ (4 wk)	79.5(68.0-91.0)	
157		26♂ (5 wk)	138(117-158)	
158		38♀ (5 wk)	113(99-128)	
159		26♂ (6 wk)	188(157-218)	
160		38♀ (6 wk)	147(128-166)	
161		26♂ (7 wk)	233(195-260)	
162		38♀ (7 wk)	172(149-195)	
163		26♂ (8 wk)	274(231-317)	
164		38♀ (8 wk)	196(169-222)	
165		26♂ (10 wk)	339(291-386)	
166		38♀ (10 wk)	227(199-256)	
167		26♂ (12 wk)	393(328-458)	
168		38♀ (12 wk)	251(232-280)	
169		26♂ (15 wk)	440(379-501)	
170		38♀ (15 wk)	274(238-310)	
171		26♂ (20 wk)	490(423-556)	
172		38♀ (20 wk)	303(270-335)	
173		38♀ (30 wk)	335(298-373)	
174		38♀ (40 wk)	358(311-404)	
175	Wistar, albino	30-50♂ (birth)	5.63	3,4
176		30-50♀ (birth)	5.3	
177		30-50♂ (3 wk)	43	
178		30-50♀ (3 wk)	41	
179		30-50♂ (4 wk)	52	
180		30-50♀ (4 wk)	55	
	Rattus norvegicus (Norway rat)			
181	Wistar, albino	30-50♂ (5 wk)	84	3,4
182		30-50♀ (5 wk)	79	
183		30-50♂ (6 wk)	110	
184		30-50♀ (6 wk)	97	
185		30-50♂ (7 wk)	141	
186		30-50♀ (7 wk)	116	
187		30-50♂ (8 wk)	170	
188		30-50♀ (8 wk)	128	
189		30-50♂ (10 wk)	200	
190		30-50♀ (10 wk)	147	
191		30-50♂ (12 wk)	225	
192		30-50♀ (12 wk)	165	
193		30-50♂ (15 wk)	251	
194		30-50♀ (15 wk)	180	
195		30-50♂ (20 wk)	280	
196		30-50♀ (20 wk)	200	
197		30-50♂ (30 wk)	322	
198		30-50♀ (30 wk)	228	
199		30-50♂ (40 wk)	342	
200		30-50♀ (40 wk)	245	
201		30-50♂ (52 wk)	364	
202		30-50♀ (52 wk)	243	
203	Wild[3]	♂ (40 da)	85(67-112)	1
204		♀ (40 da)	104(79-142)	
205		♂ (60 da)	170(127-218)	
206		♀ (60 da)	152(120-200)	
207		♂ (80 da)	237(176-299)	
208		♀ (80 da)	194(149-249)	
209		♂ (100 da)	289(217-361)	
210		♀ (100 da)	230(178-291)	
211		♂ (120 da)	330(251-408)	
212		♀ (120 da)	260(203-327)	
213		♂ (160 da)	388(302-472)	
214		♀ (160 da)	311(245-383)	
215		♂ (200 da)	424(335-509)	
216		♀ (200 da)	348(276-423)	
217		♂ (240 da)	446(358-531)	
218		♀ (240 da)	376(300-452)	
219		♂ (280 da)	460(374-545)	
220		♀ (280 da)	397(319-473)	
221		♂ (320 da)	468(385-551)	
222		♀ (320 da)	413(333-488)	
223		♂ (360 da)	474(392-556)	
224		♀ (360 da)	424(344-497)	
225		♂ (400 da)	477(397-558)	
226		♀ (400 da)	433(352-507)	
227		♂ (440 da)	480(400-560)	
228		♀ (440 da)	440(358-512)	
229		♂ (480 da)	482(402-561)	
230		♀ (480 da)	445(363-516)	

/1/ Values in parentheses (column C) are ranges, estimate "b" (cf. Introduction). /3/ Values in parentheses (column C) are the 10th and 90th percentiles.

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continued

28. GROWTH: MAMMALS

Part II. BODY WEIGHT: RODENTS

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Part III. BODY WEIGHT: MAMMALS OTHER THAN MAN AND RODENTS

	Species	Subjects (Age)	Weight kg	Reference
	(A)	(B)	(C)	(D)
	Bos taurus (cattle)			
1	Ayrshire	58♂ (birth)	36.8	3
2		100♀ (birth)	35.9	2
3		23♂ (3 mo)	74.5	3
4		81♀ (3 mo)	84.1	2
5		12♂ (6 mo)	140.9	3
6		91♀ (6 mo)	155.9	2
7		4♂ (9 mo)	205.9	3
8		75♀ (9 mo)	222.7	2
9		3♂ (12 mo)	289.1	3
10		86♀ (12 mo)	266.4	2
11		76♀ (18 mo)	354.5	2
12		72♀ (2 yr)	448.6	2
13		56♀ (3 yr)	501.4	2
14		32♀ (4 yr)	525.9	2
15		18♀ (5 yr)	550.9	2
16		8♀ (6 yr)	543.2	2
17		4♀ (7 yr)	589.5	2
18	Guernsey	25♂ (birth)	35.5	3
19		78♀ (birth)	32.7	2
20		14♂ (3 mo)	69.1	3
21		59♀ (3 mo)	69.5	2
22		8♂ (6 mo)	129.1	3
23		69♀ (6 mo)	138.2	2
24		3♂ (9 mo)	204.5	3
25		56♀ (9 mo)	201.4	2
26		68♀ (12 mo)	246.4	2
27		54♀ (18 mo)	330.0	2
28		58♀ (2 yr)	414.5	2
29		34♀ (3 yr)	469.5	2
30		21♀ (4 yr)	506.4	2
31		12♀ (5 yr)	519.5	2
32		2♀ (6 yr)	586.8	2
33		2♀ (7 yr)	526.4	2
34	Holstein	220♂ (birth)	45.5	3
35		262♀ (birth)	40.0	2
36		145♂ (3 mo)	99.1	3
37		256♀ (3 mo)	97.7	2
38		104♂ (6 mo)	190.5	3
39		247♀ (6 mo)	181.4	2
40		65♂ (9 mo)	287.3	3
41		244♀ (9 mo)	258.2	2
42		25♂ (12 mo)	370.5	3
43		242♀ (12 mo)	320.0	2
44		4♂ (18 mo)	526.8	3
45		233♀ (18 mo)	420.0	2
46		2♂ (2 yr)	640.9	3
47		215♀ (2 yr)	522.3	2
48		158♀ (3 yr)	587.3	2
49		110♀ (4 yr)	628.2	2
50		77♀ (5 yr)	653.2	2
51		53♀ (6 yr)	673.6	2
52		34♀ (7 yr)	679.1	2
	Bos taurus (cattle)			
53	Jersey	95♂ (birth)	26.4	3
54		105♀ (birth)	24.5	2
55		57♂ (3 mo)	59.1	3
56		82♀ (3 mo)	62.3	2
57		31♂ (6 mo)	114.1	3
58		97♀ (6 mo)	129.1	2
59		8♂ (9 mo)	184.1	3
60		76♀ (9 mo)	188.2	2
61		89♀ (12 mo)	231.8	2
62		78♀ (18 mo)	301.8	2
63		80♀ (2 yr)	365.5	2
64		47♀ (3 yr)	406.8	2
65		37♀ (4 yr)	441.4	2
66		22♀ (5 yr)	464.5	2
67		7♀ (6 yr)	441.8	2
68		4♀ (7 yr)	482.3	2
	Canis familiaris (dog)			
69	Basenji[1]	23♂ (birth)	0.29(0.20-0.38)	12
70		27♀ (birth)	0.27(0.22-0.32)	
71		23♂ (1 wk)	0.49(0.27-0.71)	
72		27♀ (1 wk)	0.43(0.23-0.63)	
73		23♂ (2 wk)	0.73(0.45-1.01)	
74		27♀ (2 wk)	0.65(0.41-0.89)	
75		23♂ (4 wk)	1.12(0.72-1.52)	
76		27♀ (4 wk)	0.96(0.60-1.32)	
77		23♂ (6 wk)	1.51(0.85-2.17)	
78		27♀ (6 wk)	1.37(0.87-1.87)	
79		23♂ (8 wk)	2.30(1.16-3.44)	
80		27♀ (8 wk)	2.13(1.39-2.87)	
81		23♂ (10 wk)	3.29(1.69-4.89)	
82		27♀ (10 wk)	2.96(1.87-4.05)	
83		23♂ (12 wk)	4.49(2.55-6.43)	
84		27♀ (12 wk)	3.97(2.65-5.29)	
85		23♂ (14 wk)	5.66(3.58-7.74)	
86		27♀ (14 wk)	4.97(3.71-6.23)	
87		23♂ (16 wk)	6.57(4.34-8.80)	
88		27♀ (16 wk)	5.51(4.08-6.94)	
89	Beagle[1]	39♂ (birth)	0.31(0.17-0.45)	12
90		31♀ (birth)	0.30(0.21-0.39)	
91		39♂ (1 wk)	0.55(0.37-0.73)	
92		31♀ (1 wk)	0.52(0.32-0.72)	
93		39♂ (2 wk)	0.80(0.35-1.35)	
94		31♀ (2 wk)	0.77(0.43-1.11)	
95		39♂ (4 wk)	1.30(0.52-2.08)	
96		31♀ (4 wk)	1.26(0.77-1.75)	
97		39♂ (6 wk)	2.05(1.24-2.86)	
98		31♀ (6 wk)	1.82(1.14-2.50)	
99		39♂ (8 wk)	2.95(1.62-4.28)	
100		31♀ (8 wk)	2.63(1.67-3.59)	
101		39♂ (10 wk)	3.81(1.95-5.67)	
102		31♀ (10 wk)	3.36(2.15-4.57)	
103		39♂ (12 wk)	4.80(2.60-7.00)	

/1/ Values in parentheses (column C) are ranges, estimate "b" (cf. Introduction).

continued

Part III. BODY WEIGHT: MAMMALS OTHER THAN MAN AND RODENTS

	Species	Subjects (Age)	Weight kg	Reference
	(A)	(B)	(C)	(D)
	Canis familiaris (dog)			
104	Beagle[1]	31♀ (12 wk)	4.34(2.87-5.81)	12
105		39♂ (14 wk)	5.71(3.32-8.10)	
106		31♀ (14 wk)	5.10(3.55-6.65)	
107		39♂ (16 wk)	6.52(3.54-9.50)	
108		31♀ (16 wk)	5.75(3.64-7.86)	
109	Cocker spaniel[1]	31♂ (birth)	0.24(0.17-0.31)	12
110		37♀ (birth)	0.24(0.15-0.33)	
111		31♂ (1 wk)	0.41(0.27-0.61)	
112		37♀ (1 wk)	0.41(0.24-0.58)	
113		31♂ (2 wk)	0.62(0.40-0.84)	
114		37♀ (2 wk)	0.63(0.41-0.85)	
115		31♂ (4 wk)	1.04(0.64-1.44)	
116		37♀ (4 wk)	1.05(0.66-1.44)	
117		31♂ (6 wk)	1.82(1.14-2.50)	
118		37♀ (6 wk)	1.74(0.91-2.57)	
119		31♂ (8 wk)	2.83(1.90-3.76)	
120		37♀ (8 wk)	2.56(1.86-3.26)	
121		31♂ (10 wk)	3.78(2.71-4.85)	
122		37♀ (10 wk)	3.39(2.50-4.28)	
123		31♂ (12 wk)	4.88(3.55-6.21)	
124		36♀ (12 wk)	4.27(3.33-5.21)	
125		31♂ (14 wk)	5.93(4.36-7.50)	
126		37♀ (14 wk)	5.08(3.90-6.26)	
127		31♂ (16 wk)	6.82(5.02-8.62)	
128		37♀ (16 wk)	5.77(4.39-7.15)	
129	German shepherd[2]	22♂ (birth)	0.49(0.34-0.68)	8, 16
130		22♂ (1 wk)	0.87(0.57-1.02)	
131		15♀ (1 wk)	0.50(0.34-0.64)	
132		22♂ (2 wk)	1.43(1.14-1.70)	
133		15♀ (2 wk)	0.89(0.57-1.02)	
134		22♂ (4 wk)	2.95(2.39-3.52)	
135		15♀ (4 wk)	2.02(1.48-2.27)	
136		20♂ (6 wk)	5.00(3.86-5.91)	
137		15♀ (6 wk)	3.77(3.30-4.09)	
138		♂ (8 wk)	(7.0-16.0)	
139		♀ (8 wk)	(8.0-18.0)	
140		♂ (10 wk)	(9.5-22.5)	
141		♀ (10 wk)	(9.5-24.5)	
142		♂ (12 wk)	(10.5-29.5)	
143		♀ (12 wk)	(15.5-28.0)	
144		♂ (14 wk)	(12.0-37.0)	
145		♀ (14 wk)	(16.5-31.5)	
146		♂ (16 wk)	(13.5-43.0)	
147		♀ (16 wk)	(16.5-38.0)	
148	Shetland sheepdog[1]	15♂ (birth)	0.21(0.14-0.28)	12
149		14♀ (birth)	0.20(0.11-0.29)	
150		15♂ (1 wk)	0.39(0.23-0.55)	
151		14♀ (1 wk)	0.36(0.16-0.56)	
152		15♂ (2 wk)	0.58(0.32-0.84)	
153		14♀ (2 wk)	0.55(0.24-0.86)	
154		15♂ (4 wk)	1.04(0.42-1.66)	
155		14♀ (4 wk)	0.97(0.42-1.52)	
156		15♂ (6 wk)	1.92(0.68-3.16)	
157		14♀ (6 wk)	1.67(0.57-2.77)	
158		15♂ (8 wk)	2.92(0.95-4.89)	
159		14♀ (8 wk)	2.44(0.72-4.16)	
160		15♂ (10 wk)	3.92(1.18-6.66)	
161		14♀ (10 wk)	3.23(0.81-5.65)	
162		15♂ (12 wk)	4.96(1.56-8.36)	
163		14♀ (12 wk)	4.04(0.98-7.10)	
164		15♂ (14 wk)	5.93(1.72-10.14)	
	Canis familiaris (dog)			
165	Shetland sheepdog[1]	14♀ (14 wk)	4.86(1.20-8.44)	12
166		15♂ (16 wk)	6.96(1.92-12.00)	
167		14♀ (16 wk)	5.67(1.48-9.86)	
168	Wirehaired fox terrier[1]	21♂ (birth)	0.19(0.10-0.28)	12
169		23♀ (birth)	0.19(0.14-0.24)	
170		21♂ (1 wk)	0.37(0.22-0.52)	
171		23♀ (1 wk)	0.38(0.22-0.54)	
172		21♂ (2 wk)	0.57(0.35-0.79)	
173		23♀ (2 wk)	0.56(0.35-0.77)	
174		21♂ (4 wk)	1.01(0.58-1.44)	
175		23♀ (4 wk)	0.96(0.63-1.29)	
176		21♂ (6 wk)	1.59(1.06-2.12)	
177		23♀ (6 wk)	1.48(0.92-2.04)	
178		21♂ (8 wk)	2.25(1.49-3.01)	
179		23♀ (8 wk)	2.10(1.24-2.96)	
180		21♂ (10 wk)	2.94(1.83-4.05)	
181		23♀ (10 wk)	2.71(1.58-3.84)	
182		21♂ (12 wk)	3.73(2.26-5.20)	
183		23♀ (12 wk)	3.42(2.22-4.62)	
184		21♂ (14 wk)	4.45(2.93-5.97)	
185		23♀ (14 wk)	4.02(2.66-5.38)	
186		21♂ (16 wk)	5.14(3.50-6.78)	
187		23♀ (16 wk)	4.59(3.23-5.95)	
	Capra hircus (goat)[1]			
188	Angora	♂ (birth)	3.03(2.08-3.97)	13
189		♀ (birth)	2.75(1.90-3.61)	
190		♂ (6 mo)	17.0(11.3-22.7)	
191		♀ (6 mo)	15.4(10.5-20.3)	
192		♂ (12 mo)	27.5(18.1-36.9)	
193		♀ (12 mo)	21.1(15.8-26.4)	
194		♂ (2 yr)	36.6(24.7-48.5)	
195		♀ (2 yr)	26.1(20.2-32.0)	
196		♂ (3 yr)	45.3(29.6-61.0)	
197		♀ (3 yr)	29.4(24.0-34.8)	
198		♂ (4 yr)	55.4(39.3-71.5)	
199		♀ (4 yr)	31.7(25.6-37.9)	
200		♂ (5 yr)	63.1	
201		♀ (5 yr)	33.2(26.5-39.9)	
202	British Alpine	>50♂♀ (birth)	3.75	9
203		>50♂♀ (1 mo)	9.55	
204		>50♂♀ (2 mo)	14.5	
205		>50♂♀ (4 mo)	25.9	
206		>50♂♀ (6 mo)	33.2	
207		>50♂♀ (12 mo)	49.1	
208		>50♂♀ (18 mo)	62.0	
209		>50♂♀ (21 mo)	65.5	
210	Saanen	♂ (birth)	3.60(2.36-4.84)	4
211		♀ (birth)	3.14(1.64-4.64)	
212		♂ (1 mo)	7.17(4.75-9.59)	
213		♀ (1 mo)	6.71(4.11-9.31)	
214		♂ (2 mo)	11.3(7.5-15.1)	
215		♀ (2 mo)	11.0(7.3-14.7)	
216		♂ (3 mo)	15.0(9.2-20.7)	
217		♀ (3 mo)	14.6(9.1-20.1)	
218		♂ (6 mo)	24.6(14.9-34.5)	
219		♀ (6 mo)	24.5(15.4-33.5)	
220		♂ (9 mo)	30.6(20.8-40.3)	
221		♀ (9 mo)	29.9(18.9-40.8)	
222		♂ (12 mo)	40.7(28.1-54.3)	
223		♀ (12 mo)	35.3(21.6-49.1)	
224		♂ (18 mo)	52.2(34.7-69.6)	

/1/ Values in parentheses (column C) are ranges, estimate "b" (cf. Introduction). /2/ Values in parentheses (column C) are ranges, estimate "c" (cf. Introduction), unless otherwise indicated.

continued

28. GROWTH: MAMMALS

Part III. BODY WEIGHT: MAMMALS OTHER THAN MAN AND RODENTS

	Species	Subjects (Age)	Weight kg	Reference
	(A)	(B)	(C)	(D)
	Capra hircus (goat)[1]			
225	Saanen	♀ (18 mo)	44.9(28.9-60.9)	4
226		♂ (2 yr)	58.2(29.8-86.6)	
227		♀ (2 yr)	53.7(34.1-73.4)	
228		♂ (3 yr)	67.8(33.5-102.1)	
229		♀ (3 yr)	58.4(32.9-83.9)	
230		♂ (4 yr)	81.7	
231		♀ (4 yr)	60.3(37.1-83.6)	
232		♂ (5 yr)	76.7	
233		♀ (5 yr)	70.1(37.5-102.7)	
234	Toggenburg	♂ (birth)	3.49(2.31-4.67)	4
235		♀ (birth)	3.08(2.00-4.16)	
236		♂ (1 mo)	6.76(4.48-9.04)	
237		♀ (1 mo)	6.35(4.41-8.29)	
238		♂ (2 mo)	11.2(7.9-14.4)	
239		♀ (2 mo)	10.2(7.5-13.0)	
240		♂ (3 mo)	15.0(10.1-19.9)	
241		♀ (3 mo)	13.7(10.2-17.3)	
242		♂ (6 mo)	23.3(16.8-29.8)	
243		♀ (6 mo)	20.8(14.8-26.8)	
244		♂ (9 mo)	27.2(18.7-35.7)	
245		♀ (9 mo)	25.4(18.3-32.4)	
246		♂ (12 mo)	34.8(25.8-43.8)	
247		♀ (12 mo)	29.0(21.0-36.9)	
248		♂ (18 mo)	42.6(31.9-53.3)	
249		♀ (18 mo)	38.1(26.7-49.4)	
250		♂ (2 yr)	47.9(30.9-65.0)	
251		♀ (2 yr)	45.0(28.6-61.4)	
252		♂ (3 yr)	58.2(39.7-76.8)	
253		♀ (3 yr)	51.6(31.0-72.1)	
254		♂ (4 yr)	70.9(52.3-89.4)	
255		♀ (4 yr)	51.6(33.9-69.4)	
256		♂ (5 yr)	66.5(31.2-101.8)	
257		♀ (5 yr)	54.2(39.7-68.6)	
258	*Equus caballus* (horse),	18♂ (3.1 da)	52.45	11
259	thorough-	19♀ (5.6 da)	54.32	
260	bred	3♂ (33.5 da)	93.89	
261		4♀ (83 da)	116.77	
262		8♂ (9 mo)	285.13	
263		5♂ (yearling)	306.35	
264		1♀ (yearling)	354.00	
265		2♀ (12 mo)	380.11	
266		3♂ (2-3 yr)	433.92	
267		7♀ (2-3 yr)	408.50	
268		11♂[3] (4.3 yr)	445.76	
269	*Felis catus* (cat)[2]	6♂ (birth)	0.098(0.083-0.107)	7
270		6♀ (birth)	0.104(0.097-0.120)	7
271		6♂ (1 wk)	0.129(0.083-0.196)	7
272		6♀ (1 wk)	0.144(0.097-0.212)	7
273		6♂ (2 wk)	0.213(0.146-0.282)	7
274		6♀ (2 wk)	0.230(0.162-0.296)	7
275		6♂ (3 wk)	0.297(0.259-0.365)	7
276		6♀ (3 wk)	0.324(0.267-0.377)	7
277		6♂ (4 wk)	0.364(0.266-0.487)	7
278		6♀ (4 wk)	0.402(0.330-0.475)	7
279		6♂ (5 wk)	0.446(0.346-0.578)	7
280		6♀ (5 wk)	0.467(0.387-0.563)	7
281		6♂ (6 wk)	0.541(0.420-0.625)	7
282		6♀ (6 wk)	0.540(0.467-0.623)	7
283		6♂ (7 wk)	0.642(0.515-0.767)	7
284		6♀ (7 wk)	0.622(0.521-0.701)	7
285	*Felis catus* (cat)[2]	6♂ (8 wk)	0.714(0.559-0.820)	7
286		6♀ (8 wk)	0.684(0.645-0.760)	7
287		6♂ (9 wk)	0.811(0.589-0.963)	7
288		6♀ (9 wk)	0.763(0.715-0.817)	7
289		6♂ (10 wk)	1.006(0.872-1.159)	7
290		6♀ (10 wk)	0.891(0.790-1.032)	7
291		6♂ (11 wk)	0.998(0.789-1.219)	7
292		6♀ (11 wk)	1.009(0.897-1.105)	7
293		6♂ (12 wk)	1.280(1.200-1.347)	7
294		6♀ (12 wk)	1.011(0.902-1.216)	7
295		6♂ (13 wk)	1.440(1.271-1.550)	7
296		6♀ (13 wk)	1.202(1.024-1.361)	7
297		52♂ (adult)	2.822(1.410-4.234)[1]	6
298		52♀ (adult)	2.445(1.415-3.476)[1]	6
299	*Macaca mulatta* (rhesus monkey)[2]	28♂ (birth)	0.49(0.39-0.67)	15
300		50♀ (birth)	0.47(0.33-0.64)	
301		28♂ (3 mo)	0.96(0.76-1.30)	
302		50♀ (3 mo)	0.92(0.54-1.16)	
303		28♂ (6 mo)	1.45(1.07-1.88)	
304		50♀ (6 mo)	1.42(0.89-1.80)	
305		28♂ (9 mo)	1.84(1.25-2.33)	
306		50♀ (9 mo)	1.82(1.18-2.28)	
307		28♂ (12 mo)	2.20(1.48-2.98)	
308		50♀ (12 mo)	2.19(1.45-2.68)	
309		22♂ (18 mo)	2.88(2.01-3.76)	
310		45♀ (18 mo)	2.83(1.86-3.44)	
311		17♂ (2 yr)	3.45(2.70-4.76)	
312		43♀ (2 yr)	3.41(2.40-4.35)	
313		12♂ (3 yr)	5.27(4.19-7.22)	
314		34♀ (3 yr)	4.82(3.72-5.94)	
315		10♂ (4 yr)	7.52(5.74-10.76)	
316		31♀ (4 yr)	5.95(4.80-7.21)	
317		9♂ (5 yr)	8.71(6.83-10.29)	
318		28♀ (5 yr)	6.66(5.28-9.60)	
319		7♂ (6 yr)	9.97(8.78-11.10)	
320		25♀ (6 yr)	7.29(5.65-10.90)	
321		6♂ (7 yr)	10.97(8.80-12.13)	
322		21♀ (7 yr)	8.01(6.31-12.20)	
323	*Oryctolagus cuniculus* (European rabbit), New Zealand white[2]	♂♀ (birth)	0.065	14
324		♂♀ (7 da)	0.146	
325		♂♀ (14 da)	0.260	
326		♂♀ (21 da)	0.357	
327		♂♀ (28 da)	0.584	
328		♂♀ (35 da)	0.916	
329		♂♀ (42 da)	1.25	
330		♂♀ (49 da)	1.56	
331		♂♀ (56 da)	1.75	
332		♂ (8 wk)	1.95(1.60-2.30)	
333		♀ (8 wk)	2.04(1.50-2.50)	
334		♂ (10 wk)	2.32(2.00-2.60)	
335		♀ (10 wk)	2.37(1.90-2.60)	
336		♂ (12 wk)	2.67(2.30-3.00)	
337		♀ (12 wk)	2.72(2.10-3.00)	
338		♂ (14 wk)	2.98(2.50-3.30)	
339		♀ (14 wk)	3.05(2.30-3.40)	
340		♂ (16 wk)	3.13(2.60-3.50)	
341		♀ (16 wk)	3.26(2.60-3.70)	
342		♂ (18 wk)	3.3(2.8-3.7)	
343		♀ (18 wk)	3.49(2.90-4.00)	
344		♂ (20 wk)	3.45(2.80-3.90)	
345		♀ (20 wk)	3.7(3.0-4.3)	

/1/ Values in parentheses (column C) are ranges, estimate "b" (cf. Introduction). /2/ Values in parentheses (column C) are ranges, estimate "c" (cf. Introduction), unless otherwise indicated. /3/ Geldings.

continued

Part III. BODY WEIGHT: MAMMALS OTHER THAN MAN AND RODENTS

	Species	Subjects (Age)	Weight kg	Reference
	(A)	(B)	(C)	(D)
346	*Oryctolagus cuniculus* (European rabbit), New Zealand white[2]	♂ (22 wk)	3.53(3.00-4.00)	14
347		♀ (22 wk)	3.85(3.30-4.40)	
348		♂ (24 wk)	3.61(3.00-4.30)	
349		♀ (24 wk)	4.0(3.4-4.8)	
350		♂ (26 wk)	3.73(3.00-4.40)	
351		♀ (26 wk)	4.08(3.50-4.90)	
	Ovis aries (sheep)[4]			10
352	Corriedale	♂ (birth)	3.7; 4.4	
353		♀ (birth)	3.3; 4.0	
354		♂ (3 mo)	20.5; 24.7	
355		♀ (3 mo)	17.8; 20.9	
356		♂ (6 mo)	32.9; 36.6	
357		♀ (6 mo)	26.9; 30.5	
358		♂ (12 mo)	55.9; 56.0	
359		♀ (12 mo)	43.3; 46.0	
360	Hampshire	♂ (birth)	4.5; 5.1	
361		♀ (birth)	4.1; 4.5	
362		♂ (3 mo)	26.5; 30.1	
363		♀ (3 mo)	23.1; 27.0	
364		♂ (6 mo)	37.2; 42.2	
365		♀ (6 mo)	32.6; 36.5	
366		♂ (12 mo)	64.5; 66.3	
367		♀ (12 mo)	54.2; 57.7	
368	Shropshire	♂ (birth)	3.5; 4.4	
369		♀ (birth)	3.2; 3.8	
370		♂ (3 mo)	20.0; 22.4	
371		♀ (3 mo)	17.5; 20.6	
372		♂ (6 mo)	28.6; 30.4	
373		♀ (6 mo)	25.7; 28.9	
374		♂ (12 mo)	53.2; 55.1	
375		♀ (12 mo)	42.8; 48.3	
376	Southdown	♂ (birth)	3.6; 3.9	
377		♀ (birth)	3.0; 3.6	
378		♂ (3 mo)	19.0; 20.8	
379		♀ (3 mo)	15.5; 18.4	
380		♂ (6 mo)	26.4; 29.0	
381		♀ (6 mo)	22.6; 25.4	
382		♂ (12 mo)	43.3; 47.3	
	Ovis aries (sheep)[4]			10
383	Southdown	♀ (12 mo)	38.4; 40.8	
	Sus scrofa (swine)[2]			
384	Berkshire	7 (birth)	1.84(1.34-2.17)	5
385		7 (1 wk)	2.58(2.17-3.10)	
386		7 (2 wk)	4.32(3.76-4.91)	
387		7 (3 wk)	7.02(5.78-8.14)	
388		7 (4 wk)	9.85(8.43-12.60)	
389		7 (5 wk)	14.02(12.30-17.00)	
390		7 (6 wk)	18.31(16.14-21.36)	
391		7 (7 wk)	23.16(21.02-27.04)	
392		7 (8 wk)	27.45(24.32-31.36)	
393	Duroc-Jersey	2 (birth)	(2.73-2.76)	5
394		2 (1 wk)	(2.96-3.64)	
395		2 (2 wk)	(4.75-5.74)	
396		2 (3 wk)	(6.84-8.03)	
397		2 (4 wk)	(8.55-9.12)	
398		2 (5 wk)	(12.80-13.45)	
399		2 (6 wk)	(16.50-17.45)	
400		2 (7 wk)	(20.43-21.45)	
401		2 (8 wk)	(23.86-24.55)	
402		2 (9 wk)	(31.0-32.0)	
403		2 (10 wk)	(36.8-38.0)	
404		2 (11 wk)	(43.4-44.5)	
405		2 (12 wk)	(50.0-51.5)	
406		2 (13 wk)	(56.7-58.5)	
407	Yorkshire	154 (birth)	1.23	1
408		127 (8 wk)	11.8	
409		191 (10 wk)	16.3	
410		64 (12 wk)	20.4	
411		142 (14 wk)	27.2	
412		85 (16 wk)	35.8	
413		97 (18 wk)	46.2	
414		61 (20 wk)	47.6	
415		220 (22 wk)	65.2	
416		80 (24 wk)	78.8	
417		136 (26 wk)	79.3	
418		64 (28 wk)	87.9	

/2/ Values in parentheses (column C) are ranges, estimate "c" (cf. Introduction), unless otherwise indicated.
/4/ First value (column C) is for twin-birth animals, second value is for single-birth animals.

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29. GROWTH: VERTEBRATES OTHER THAN MAMMALS

For information on organ weights of chicken, and for information on additional species of reptiles, amphibians and fishes, consult reference 2, Part I.

Part I. BODY WEIGHT: BIRDS

	Species	Age	Weight kg: Males	Weight kg: Females	Reference
	(A)	(B)	(C)	(D)	(E)
1	*Anas platyrhynchos*	Hatched	0.059		5
2	*domesticus* (Pekin	1 wk	0.150		
3	duck)[1]	2 wk	0.458		
4		3 wk	0.744		
5		4 wk	1.148		
6		5 wk	1.506		
7		6 wk	2.005		
8		8 wk	2.758		
9	*Anser anser* (gray-	Hatched	......	0.077	1
10	lag goose)	1 wk	0.227	0.227	
11		2 wk	0.635	0.589	
12		3 wk	1.270	1.270	
13		4 wk	1.905	1.769	
14		5 wk	2.404	1.814	
15		6 wk	3.039	2.585	
16		8 wk	3.946	3.447	
17		10 wk	4.264	3.719	
18		12 wk	5.035	4.218	
19		16 wk	5.352	4.672	
20	*Colinus virginianus*	Hatched	0.004		3
21	(bobwhite quail)[1]	1 wk	0.018		
22		2 wk	0.027		
23		3 wk	0.045		
24		4 wk	0.063		
25		5 wk	0.082		
26		6 wk	0.095		
27		8 wk	0.132		
28		12 wk	0.159		
29		16 wk	0.172		
	Gallus domesticus (chicken)				
30	Cornish	Hatched	0.032	0.032	4
31		1 wk	0.059	0.059	
32		2 wk	0.109	0.105	
33		3 wk	0.182	0.172	
34		4 wk	0.268	0.256	
35		8 wk	0.727	0.636	
36		12 wk	1.272	1.045	
37		16 wk	1.727	1.318	
38		20 wk	2.091	1.545	
39	New Hampshire	Hatched	0.041	0.036	6
40		1 wk	0.086	0.082	
41		2 wk	0.154	0.154	
42		3 wk	0.272	0.250	
43		4 wk	0.404	0.363	
44		5 wk	0.563	0.504	
45		6 wk	0.735	0.640	
46		7 wk	0.934	0.807	
47		8 wk	1.152	0.948	
48		9 wk	1.325	1.107	
49		10 wk	1.628	1.284	
50		12 wk	1.849	1.551	
51		14 wk	2.554	1.828	
52		16 wk	2.994	2.019	
53		18 wk	3.293	2.254	
54		20 wk	3.375	2.309	
55	White Leghorn	Hatched	0.036	0.036	6
56		1 wk	0.059	0.073	
57		2 wk	0.123	0.118	
58		3 wk	0.191	0.195	
59		4 wk	0.268	0.272	
	Gallus domesticus (chicken)				
60	White Leghorn	5 wk	0.354	0.367	6
61		6 wk	0.449	0.436	
62		7 wk	0.603	0.549	
63		8 wk	0.689	0.640	
64		9 wk	0.875	0.721	
65		10 wk	0.944	0.776	
66		12 wk	1.243	0.934	
67		14 wk	......	1.107	
68		16 wk	......	1.270	
69		18 wk	......	1.402	
70		20 wk	......	1.551	
	Meleagris gallopavo (turkey)				
71	Beltsville Small	Hatched	0.045	0.045	6
72	White	1 wk	0.095	0.086	
73		2 wk	0.181	0.163	
74		4 wk	0.472	0.404	
75		6 wk	0.921	0.721	
76		8 wk	1.483	1.148	
77		10 wk	2.205	1.674	
78		12 wk	2.726	2.087	
79		14 wk	3.357	2.608	
80		16 wk	4.264	3.062	
81		18 wk	4.704	3.357	
82		20 wk	5.643	3.742	
83		24 wk	7.438	4.382	
84		26 wk	8.038	4.631	
85		28 wk	9.008	4.740	
86		30 wk	9.113	5.085	
87	Broad-Breasted	Hatched	0.054	0.050	6
88	Bronze	1 wk	0.113	0.109	
89		2 wk	0.204	0.195	
90		4 wk	0.585	0.517	
91		6 wk	1.252	0.998	
92		8 wk	2.028	1.651	
93		10 wk	2.939	2.354	
94		12 wk	4.037	3.166	
95		14 wk	4.922	3.715	
96		16 wk	6.214	4.604	
97		18 wk	6.985	5.121	
98		20 wk	8.328	5.851	
99		22 wk	8.850	6.083	
100		24 wk	10.614	6.836	
101		26 wk	11.508	7.307	
102		28 wk	12.633	7.625	
103		36 wk	14.710	7.997	
104		40 wk	14.814	8.437	
105	Eastern wild	Hatched	0.04	0.04	7
106		2 wk	0.08	0.08	
107		4 wk	0.28	0.25	
108		6 wk	0.56	0.48	
109		8 wk	0.85	0.69	
110		10 wk	1.22	0.96	
111		12 wk	1.64	1.24	
112		14 wk	2.10	1.58	
113		16 wk	2.60	1.98	
114		18 wk	3.32	2.52	
115		20 wk	4.05	3.00	
116		22 wk	4.62	3.32	
117		24 wk	5.10	3.48	

/1/ Values are for males and females combined.

continued

29. GROWTH: VERTEBRATES OTHER THAN MAMMALS

Part I. BODY WEIGHT: BIRDS

	Species	Age	Weight kg Males	Weight kg Females	Reference
	(A)	(B)	(C)	(D)	(E)
	Meleagris gallopavo (turkey)				
118	Eastern wild	26 wk	5.50	3.62	7
119		28 wk	5.78	3.71	
120		30 wk	5.95	3.77	
	Meleagris gallopavo (turkey)				
121	Eastern wild	36 wk	6.26	3.91	7
122		40 wk	6.35	3.96	

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Part II. BODY LENGTH: REPTILES AND AMPHIBIANS

Values give snout-to-vent length, unless otherwise indicated. **Subjects** (column B): GS = growing season. Values in parentheses are ranges, estimate "c" (cf. Introduction).

	Species (Common Name) [Location]	Subjects (Age)	Length mm	Reference
	(A)	(B)	(C)	(D)
	Reptilia			
1	*Ancistrodon contortrix mokeson* (northern U.S. copperhead) [Kansas]	(birth)	220(200-299)	8
2		♂ (1 yr)	354(300-409)	
3		♀ (1 yr)	345(300-390)	
4		♂ (2 yr)	480(410-530)	
5		♀ (2 yr)	450(391-510)	
6		♂ (3 yr)	560(531-589)	
7		♀ (3 yr)	538(511-565)	
8		♂ (4 yr)	620(590-650)	
9		♀ (4 yr)	578(566-589)	
10		♂ (5 yr)	668(651-684)	
11		♀ (5 yr)	598(590-615)	
12		♂ (6 yr)	710(685-734)	
13		♀ (6 yr)	626(616-635)	
14		♂ (7 yr)	760(735-785)	
15		♀ (7 yr)	643(636-650)	
16		♂ (8+ yr)	>786	
17		♀ (8+ yr)	>651	
18	*Anolis carolinensis* (American "chameleon") [Louisiana]	(hatchling)	(22-25)	9
19		(8 mo)	40	
20		(12 mo)	(35-45)	
21		♀ (18 mo)	(45-48)	
22		(21 mo)	(50-52)	
23		♂ (24 mo)	60	
24	*Crotalus viridis lutosus* (Great Basin rattlesnake) [Utah]	20♂ (1 yr)	457.2(365-498)	16
25		14♀ (1 yr)	449.5(419-503)	
26		4♂ (2 yr)	556.8(492-627)	
27		2♀ (2 yr)	553.7(530-574)	
28		6♂ (3 yr)	655.3(609-711)	
29	*Crotalus viridis lutosus* (Great Basin rattlesnake) [Utah]	1♀ (3 yr)	685.8	16
30		2♂ (4 yr)	701.0(678-724)	
31		2♀ (4 yr)	662.9(642-681)	
32		2♂ (5 yr)	703.6(645-762)	
33		2♂ (6 yr)	769.6(724-815)	
34		1♀ (6 yr)	665.5	
35		1♂ (8 yr)	909.3	
36		2♀ (8 yr)	713.7(711-716)	
37		1♂ (9 yr)	833.1	
38	*Eumeces fasciatus* (five-lined skink) [Kansas]	(hatchling)	(23-27)	6, 7
39		1 (<2 wk)	27	
40		1♂ (3 wk)	34	
41		1 (1 mo)	36	
42		1♂ (8.5 mo)	43	
43		1♂ (9 mo)	46.5	
44		3♀ (9 mo)	49(46.0-50.5)	
45		1♂ (10 mo)	48	
46		1♀ (10 mo)	48	
47		2♂ (11 mo)	58.7(52.5-65.0)	
48		2♀ (11 mo)	52.7(51.0-54.5)	
49		1♂ (12 mo)	61	
50		1♀ (12 mo)	59	
51		2♂ (13 mo)	60(56-64)	
52		1♀ (13 mo)	64	
53		1♂ (14 mo)	66	
54		1♂ (21 mo)	72.5	
55		4♂ (22 mo)	69(67-73)	
56		3♀ (22 mo)	74	
57		2♂ (24 mo)	71(70-72)	
58		2♀ (26 mo)	71.5(69-74)	

continued

29. GROWTH: VERTEBRATES OTHER THAN MAMMALS

Part II. BODY LENGTH: REPTILES AND AMPHIBIANS

	Species (Common Name) [Location]	Subjects (Age)	Length mm	Reference
	(A)	(B)	(C)	(D)
	Reptilia			
59	*Eumeces fasci-*	2♂ (33 mo)	76.5(73-80)	6, 7
60	*atus* (five-	2♀ (33 mo)	78	
61	lined skink)	1♂ (34 mo)	78	
62	[Kansas]	2♀ (34 mo)	77(76-78)	
63		1♀ (35 mo)	73	
64		1♀ (37 mo)	79.5	
65		2♂ (45 mo)	78(74-82)	
66		2♀ (45 mo)	80	
67		1♂ (57 mo)	82	
68		1♂ (>9 yr)	80	
69	*Malaclemys*	12 (hatchling)	(18.0-35.7)	3
70	*terrapin pile-*	12 (end 1st GS)	(30.3-61.1)	
71	*ata*	12 (end 2nd GS)	(54.4-86.7)	
72	(Mississippi	12 (end 3rd GS)	(65.4-107.3)	
73	diamondback	10 (end 4th GS)	(91.1-115.5)	
74	terrapin)[1]	6 (end 5th GS)	(102.5-117.5)	
75	[Louisiana]	2 (end 6th GS)	(109.9-115.0)	
76		57♂ (adult)	(98.7-123.0)	
77		2♀ (adult)	176.5(176-177)	
78	*Natrix septem-*	12 (newborn)	183(166-225)	15
79	*vittata* (queen	12 (3 mo)	230.5(196-255)	
80	snake)[2] [Ohio]	17 (1 yr)	325.2(256-375)	
81		68♂ (>2 yr)	529(375-692)	
82		58♀ (>2 yr)	584(375-787)	
	Sternotherus odoratus (musk turtle)[3]			
83	[Indiana]	2 broods (hatchling)	(18.3-22.0)	1, 5, 13
84		2 broods (3 da)	(18.6-22.2)	
85		2 broods (5 da)	(19.3-22.5)	
86		2 broods (7 da)	(19.5-22.7)	
87		2 broods (9 da)	(19.6-23.2)	
88		2 broods (11 da)	(19.7-23.4)	
89		2 broods (14 da)	(19.7-23.4)	
90		2 broods (30 da)	(19.9-23.7)	
91	[Iowa]	4 (hatchling)	22.8(22-24)	
92		3♀ (adult)	97(80-108)	
93	[Michigan]	200 (hatchling)	23(19-25)	
94		9 (6 mo)	32.5(26-37)	
95		4 (1.5 yr)	42.5(39-45)	
96		9 (2.5 yr)	52(48-55)	
97		10 (3.5 yr)	61.5(56.5-64.0)	
98		11 (4.5 yr)	67(64-70)	
99		15 (5.5 yr)	72(69-75)	
100		12 (6.5 yr)	74.5(72-78)	
101		5 (7.5 yr)	78(74.5-80.0)	
102		(8+ yr)	>80	
103	*Terrapene or-*	46♂ (1 yr)	45(27-64)	11
104	*nata* (ornate	65♀ (1 yr)	43(26-62)	
105	box turtle)[1]	47♂ (2 yr)	57(35-72)	
106	[Kansas]	67♀ (2 yr)	55(34-74)	
107		48♂ (3 yr)	66(37-86)	
108		66♀ (3 yr)	65(42-80)	
109		48♂ (4 yr)	75(53-96)	
110		67♀ (4 yr)	72(56-94)	
111		46♂ (5 yr)	84(64-114)	
112		67♀ (5 yr)	80(61-102)	
113		38♂ (6 yr)	92(66-108)	
114		63♀ (6 yr)	87(67-115)	
115		32♂ (7 yr)	97(70-114)	
116	*Terrapene or-*	59♀ (7 yr)	94(76-117)	11
117	*nata* (ornate	30♂ (8 yr)	102(82-118)	
118	box turtle)[1]	47♀ (8 yr)	102(81-125)	
119	[Kansas]	22♂ (9 yr)	106(83-119)	
120		35♀ (9 yr)	107(89-129)	
121		19♂ (10 yr)	109(92-119)	
122		29♀ (10 yr)	111(94-135)	
123		15♂ (11 yr)	112(97-121)	
124		17♀ (11 yr)	114(95-129)	
125		9♂ (12 yr)	115(99-121)	
126		12♀ (12 yr)	118(111-131)	
127		7♀ (13 yr)	120(114-129)	
128	*Thamnophis*	40♂ (newborn)	141.2(118-151)	4, 12
129	*sirtalis* (com-	38♀ (newborn)	139.5(117-151)	
130	mon garter	♂ (1 yr)	350	
131	snake)	♀ (1 yr)	370	
132	[Michigan]	♂ (2 yr)	430	
133		♀ (2 yr)	480	
134		♂ (3 yr)	480	
135		♀ (3 yr)	550	
136		♂ (4 yr)	520	
137		♀ (4 yr)	590	
138		♂ (5 yr)	550	
139		♀ (5 yr)	640	
140		♂ (6 yr)	580	
141		♀ (6 yr)	670	
142		♂ (7 yr)	590	
143		♀ (7 yr)	690	
144		♂ (8 yr)	600	
145		♀ (8 yr)	700	
	Amphibia			
146	*Bufo valliceps* (Mexican toad)	16♂ ("August" juvenile)	20.8(13-34)	2
147	[Texas]	5♀ ("August" juvenile)	26(15-38)	
148		1♀ (1 mo later)	53	
149		1♂ (2 mo later)	55	
150		8♂ (8 mo later)	68.2(61-78)	
151		5♂ (9 mo later)	72.6(64-77)	
152		2♀ (10 mo later)	94(93-95)	
153		5♂ (11 mo later)	78.2(71-86)	
154		2♀ (11 mo later)	99.5(97-102)	
155		6♂ (12 mo later)	79.8(75-88)	
156		3♀ (13 mo later)	82.5(70-104)	
157	*Hyla regilla* (Pacific tree	1,156 (just transformed)	13.8(12.1-15.3)	10
158	frog) [Oregon]	5 (2 wk)	19.8(18-21)	
159		4 (3 wk)	22(19-25)	
160		6 (4 wk)	20.3(17-23)	
161		6 (5 wk)	21.9(20-24)	
162		7 (6 wk)	21.9(20-24)	
163		1 (7 wk)	23	
164		1 (8 wk)	21	
165		2♂ (9 mo)	31(29.4-32.6)	
166		38 (>2 yr)	38.6(37-40)	
167	*Rana catesbei-ana* (American	(at transformation)	52(36-60)	14
168	bullfrog)[2]	(8 mo)	55(39-64)	
169	[New York]	(9 mo)	62(45-70)	
170		(10 mo)	73(46-82)	

/1/ Plastron length. /2/ Total length. /3/ Carapace length.

continued

29. GROWTH: VERTEBRATES OTHER THAN MAMMALS

Part II. BODY LENGTH: REPTILES AND AMPHIBIANS

	Species (Common Name) [Location]	Subjects (Age)	Length mm	Reference
	(A)	(B)	(C)	(D)
	Amphibia			
171	*Rana catesbeiana* (American bullfrog)[a] [New York]	(11 mo)	74(47-94)	14
172		(12 mo)	86(59-106)	
173		(13 mo)	92(65-112)	
174		(15 mo)	94(68-114)	
175		♂ (adult)	>85	
176		♀ (adult)	>90	
177	*R. pipiens* (leopard frog) [New York]	(at transformation)	25(20.0-30.5)	14
178		(1 mo)	33(28-39)	
179		(2 mo)	41(36-48)	
180		(3 mo)	46(40-53)	
181		♂ (15 mo)	(52-82)	
182		♀ (15 mo)	(54.0-92.5)	

/a/ Total length.

Contributor: Hardy, Ross

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Part III. BODY LENGTH AND WEIGHT: FISHES

Age (column B): Ages are completed years; Max. = age at maximum length and/or weight. Length measurements give total length--from tip of head (jaws closed) to tip of tail--unless otherwise indicated.

	Species (Common Name)	Age	Length cm	Weight kg	Reference
	(A)	(B)	(C)	(D)	(E)
	Pisces				
1	*Acipenser fulvescens* (lake sturgeon)[1]	1 yr	24	0.068	5,6,17, 31
2		2 yr	30	0.136	
3		4 yr	45	0.39	
4		6 yr	54	0.72	
5		8 yr	60	1	
6		10 yr	71	1.4	
7		Max.	168	50	
8	*Carassius auratus* (goldfish)	1 yr	9	.....	9
9		2 yr	14	.....	
10	*Clupea pallasi* (Pacific herring)[1]	1 yr	6	.....	23
11		2 yr	14	.....	
12		4 yr	21	.....	
13		6 yr	24	.....	
14		8 yr	26	.....	
15		10 yr	28	.....	
16		Max.	40	0.31	
17	*Coregonus clupeaformis* (North American lake whitefish)	1 yr	15	0.03	5,19,32
18		2 yr	23	0.085	
19		4 yr	42	0.7	
20		6 yr	53	1.36	
21	*Coregonus clupeaformis* (North American lake whitefish)	8 yr	58	2.27	5,19,32
22		10 yr	64	2.78	
23		Max.	71[1]	4.88	
24	*Cyprinus carpio* (carp)	1 yr	18	0.09	5,11,14
25		2 yr	31	0.45	
26		4 yr	48	1.8	
27		6 yr	53	2.5	
28		8 yr	58	3.2	
29		10 yr	66	5.1	
30		Max.	127	37.88	
31	*Esox lucius* (northern pike)	1 yr	20	0.09	5,11
32		2 yr	38	0.27	
33		4 yr	61	1.1	
34		6 yr	79	2.1	
35		8 yr	97	2.95	
36		10 yr	107	4.5	
37		Max.	120	28	
38	*Gadus morhua* (Atlantic cod)	1 yr	16	.....	14,27
39		2 yr	41	.....	
40		4 yr	64	.....	
41		6 yr	81	.....	
42		Max.	142	25	

/1/ Fork length, measured from tip of snout to end of rays in center of caudal fin.

continued

29. GROWTH: VERTEBRATES OTHER THAN MAMMALS

Part III. BODY LENGTH AND WEIGHT: FISHES

	Species (Common Name)	Age	Length cm	Weight kg	Reference
	(A)	(B)	(C)	(D)	(E)
	Pisces				
43	*Ictalurus punctatus* (channel catfish)	1 yr	8	0.045	5,14
44		2 yr	15	0.135	
45		4 yr	30	0.23	
46		6 yr	41	0.68	
47		8 yr	53	1.63	
48		10 yr	69	4.3	
49		Max.	127	24.05	
50	*Lepisosteus osseus* (longnose gar)	1 yr	16	.....	2,5,21,22
51		2 yr	32	.....	
52		10 yr	102	.....	
53		Max.	160	18	
54	*Lepomis macrochirus* (bluegill)	1 yr	5	0.005	5,13
55		2 yr	9	0.026	
56		4 yr	16	0.07	
57		6 yr	20	0.17	
58		8 yr	23	0.34	
59		10 yr	23	0.34	
60		Max.	39	1.955	
61	*Melanogrammus aeglefinus* (haddock)[1]	1 yr	20	.....	28,29
62		2 yr	30	0.29	
63		4 yr	45	0.9	
64		6 yr	55	1.53	
65		8 yr	61	.....	
66		Max.	90	.....	
67	*Micropterus salmoides* (largemouth black bass)	1 yr	11	0.023	5,18
68		2 yr	20	0.12	
69		4 yr	34	0.57	
70		6 yr	41	1.02	
71		8 yr	46	1.36	
72		10 yr	51	1.81	
73		Max.	95	10.48	
74	*Osmerus mordax* (American smelt)	1 yr	14	0.023	4,5,25
75		2 yr	18	0.036	
76		4 yr	25	0.11	
77		Max.	36	0.141	
78	*Perca flavescens* (yellow perch)	1 yr	7	0.003	5,14,30
79		2 yr	12	0.03	
80		4 yr	20	0.11	
81		6 yr	25	0.23	
82		8 yr	27	0.285	
83	*Perca flavescens* (yellow perch)	10 yr	30	0.37	5,14,30
84		Max.	41.9	1.913	
85	*Polyodon spathula* (paddlefish)[2]	1 yr	25	0.077	1,5,10,12
86		2 yr	64	1.35	
87		4 yr	84	2.27	
88		6 yr	97	3.4	
89		8 yr	102	5	
90		10 yr	112	6.8	
91		Max.	188[3]	74	
92	*Pomoxis annularis* (white crappie)	1 yr	7	0.006	5,16,26
93		2 yr	15	0.03	
94		4 yr	25	0.21	
95		6 yr	32	0.45	
96		8 yr	38	0.71	
97		Max.	40	0.865	
98	*Salmo salar* (Atlantic salmon)[1]	1 yr	4	0.011	5,7,14
99		2 yr	10	0.033	
100		4 yr	76	4.54	
101		6 yr	107	16	
102		Max.	120	47	
103	*S. trutta* (brown trout)	1 yr	10	0.025	5,14,15
104		2 yr	20	0.095	
105		4 yr	36	0.88	
106		6 yr	56	1.8	
107		8 yr	64	4.26	
108		Max.	120	18.5	
109	*Salvelinus fontinalis* (eastern brook trout)	1 yr	10	0.025	5,8
110		2 yr	16	0.06	
111		4 yr	35	0.65	
112		6 yr	53	1.59	
113		8 yr	56	.....	
114		Max.	80	6.58	
115	*Thunnus thynnus* (bluefin tuna)[1]	1 yr	64	.....	20,24,34
116		2 yr	82	.....	
117		4 yr	118	.....	
118		6 yr	153	.....	
119		Max.	311	726	
	Agnatha				
120	*Petromyzon marinus* (sea lamprey)	1 yr	3.8	.....	3,33
121		2 yr	7.9	.....	
122		4 yr	43	.....	
123		Max.	84	1.14	

/1/ Fork length, measured from tip of snout to end of rays in center of caudal fin. /2/ Standard length, measured from tip of snout (upper jaw) to end of vertebral column. /3/ Total length.

Contributor: Carlander, Kenneth D.

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30. LIFE SPANS: ANIMALS

For information on additional species, consult reference 1, Part I. Life spans are for animals in captivity, unless otherwise indicated.

Part I. VERTEBRATES

	Species	Common Name	Recorded Maximum Life Span	Reference
	(A)	(B)	(C)	(D)
	Mammalia			
1	*Homo sapiens*	Man	♂66.5 yr, ♀73 yr[1]	50
2	*Balaenoptera physalus*	Finback whale	36 yr	28
3	*Bos taurus*	Cattle	30 yr	15
4	*Camelus bactrianus*	Bactrian camel	>25 yr 5 mo	15
5	*Canis familiaris*	Dog	34 yr	27
6	*Capra hircus*	Goat	18 yr	15,26
7	*Cavia porcellus*	Guinea pig	>6 yr	15
8	*Didelphis marsupialis virginiana*	Virginia opossum	>7 yr	15
9	*Elaphas maximus*	Asiatic elephant	57 yr	20
10	*Equus caballus*	Horse	50 yr	15
11	*Erinaceus europaeus*	European hedgehog	>3 yr 11 mo	33
12	*Euphractus villosus*	Six-banded armadillo	18 yr	15
13	*Felis catus*	Cat	21 yr	49
14	*Macaca mulatta*	Rhesus monkey	29 yr	9,15
15	*Mesocricetus auratus*	Golden hamster	1 yr 9 mo	9
16	*Mus musculus*	House mouse	>3 yr	22,46
17	*Mustela vison*	Mink	10 yr	40
18	*Myotis lucifugus*	Little brown bat	22 yr 10 mo[2]	35
19	*Ondatra zibethica*	Muskrat	6 yr 3 mo	38
20	*Ornithorhynchus anatinus*	Platypus	14 yr	34
21	*Oryctolagus cuniculus*	European rabbit	>13 yr	15
22	*Ovis aries*	Sheep	20 yr	26,38
23	*Phoca vitulina*	Harbor seal	19 yr	4
24	*Procyon lotor*	Raccoon	>13 yr 9 mo	15
25	*Rattus norvegicus*	Rat (albino)	>3 yr 4 mo	9,21
26	*Sciurus carolinensis*	Gray squirrel	14-15 yr	15
27	*Sorex palustris*	Water shrew	1 yr 6 mo	40
28	*Sus scrofa*	Swine	27 yr	26
29	*Tamias striatus*	Eastern chipmunk	7 yr 6 mo	38
	Aves			
30	*Anas platyrhynchos*	Mallard duck	19 yr[3]	19
31			20 yr 6 mo[2]	30
32	*Anser domesticus*	Common goose	31 yr	14
33	*Aptenodytes patagonica*	King penguin	26 yr	19
34	*Columba leucocephala*	White-crowned pigeon	8 yr 3 mo[2]	30
35	*C. livia*	Street pigeon	35 yr	14
36	*Corvus brachyrhynchos*	American crow	13 yr 9 mo[2]	30
37	*C. corax*	Raven	69 yr	38
38	*Cygnus buccinator*	Trumpeter swan	>29 yr 5 mo	19
39	*Gallus domesticus*	Chicken	30 yr	38
40	*Gyps fulvus*	Griffon vulture	>41 yr 5 mo	7
41	*Larus argentatus*	Herring gull	>44 yr	14,38
42			19 yr[2]	30
43	*Meleagris gallopavo*	Turkey	12 yr 4 mo	19
44	*Passer italiae*	Italian sparrow	20 yr	38

/1/ Values are for average life span. /2/ In natural habitat. /3/ Still alive at time of report.

continued

30. LIFE SPANS: ANIMALS

Part I. VERTEBRATES

	Species	Common Name	Recorded Maximum Life Span	Reference
	(A)	(B)	(C)	(D)
	Aves			
45	*Perdix perdix*	European partridge	>5 yr	19
46	*Phasianus colchicus*	Ring-necked pheasant	27 yr	14
47	*Serinus canarius*	Canary	24 yr	26
48	*Struthio camelus*	African ostrich	50 yr	26
49	*Sturnus vulgaris*	Starling	>15 yr 10 mo	38
50			8 yr[2]	30
51	*Turdus migratorius*	American robin	12 yr 10 mo	38
52			12 yr 6 mo[2]	38
	Reptilia			
53	*Alligator mississipiensis*	American alligator	>56 yr[3]	18
54	*Ancistrodon contortrix mokeson*	Northern U.S. copperhead	18 yr 6 mo[3]	41
55	*Anguis fragilis*	Slowworm	32 yr	18
56	*Anolis equestris*	Giant Cuban "chameleon"	3 yr 5 mo	6
57	*Caretta caretta*	Loggerhead turtle	33 yr	6
58	*Chalcides ocellatus*	Sand skink	9 yr 6 mo	18
59	*Chelydra serpentina*	Snapping turtle	20 yr	18
60	*Coluber constrictor*	American black snake	5 yr 4 mo[3]	32
61	*Crotalus viridis helleri*	Southern Pacific rattlesnake	19 yr 5 mo	44
62	*Heloderma suspectum*	Gila monster	24 yr 7 mo	8
63	*Malaclemys terrapin centrata*	Southern diamondback terrapin	>21 yr[3]	18
64	*Naja naja*	Indian cobra	12 yr 4 mo	6
65	*Natrix sipedon*	North American water snake	7 yr	18
66	*Pseudemys scripta elegans*	Red-eared turtle	7 yr 1 mo	32
67	*Sceloporus graciosus*	Sagebrush lizard	8 yr	48
68	*Sphenodon punctatus*	Tuatara	>28 yr[3]	13
69	*Sternotherus odoratus*	Musk turtle	53 yr 3 mo[3]	6
70	*Terrapene carolina*	Box turtle	83-88 yr	18
71	*Thamnophis sirtalis*	Common garter snake	6 yr	32
	Amphibia			
72	*Ambystoma maculatum*	Spotted salamander	>24 yr	17
73	*A. tigrinum*	Tiger salamander	11 yr	17
74	*Amphiuma means*	Two-toed amphiuma	>26 yr 9 mo	12,17
75	*Bufo americanus*	American toad	10-15 yr	12
76	*B. arenarum*	Sand toad	>7 yr 5 mo	12
77	*Cryptobranchus alleganiensis*	Hellbender	>28 yr 7 mo	17
78	*Hyla arborea*	Tree frog	14 yr 1 mo	12,17
79	*Necturus maculosus*	Mud puppy	>8 yr 10 mo	17
80	*Pipa pipa*	Surinam toad	7 yr 10 mo[3]	17
81	*Rana catesbeiana*	American bullfrog	>15 yr 8 mo	17
82	*R. pipiens*	Leopard frog	>5 yr 11 mo	17
83	*Triturus cristatus*	Crested newt	>4 yr 1 mo	12
84	*T. viridescens*	Common newt	>2 yr 11 mo	12
85	*Xenopus laevis*	Clawed toad	15 yr	17
	Pisces			
86	*Acipenser fulvescens*	Lake sturgeon	152 yr[2]	2
87	*A. ruthenus*	Sterlet	>46 yr 1 mo	16
88	*Amia calva*	Bowfin	24 yr	16
89			30 yr[2]	5
90	*Anguilla anguilla*	European freshwater eel	15 yr[2]	23
91	*A. rostrata*	American freshwater eel	50 yr	11
92	*Carassius auratus*	Goldfish	30 yr	11,16
93	*Clupea harengus*	Atlantic herring	19 yr[2]	16
94	*Coregonus clupeaformis*	North American lake whitefish	12 yr	16
95			26 yr[2]	24
96	*Cyprinus carpio*	Carp	47 yr	16
97	*Electrophorus electricus*	Electric eel	>11 yr 6 mo	11
98	*Esox lucius*	Northern pike	10 yr	11
99			24 yr[2]	37
100	*Gadus morhua*	Atlantic cod	16 yr[2]	10
101	*Hippocampus hudsonius*	Atlantic sea horse	>4 yr 7 mo	11
102	*Hippoglossus hippoglossus*	Atlantic halibut	40 yr[2]	16
103	*Ictalurus catus*	White catfish	>8 yr 1 mo	11
104	*I. punctatus*	Channel catfish	13 yr[2]	29
105	*Lepidosiren paradoxa*	South American lungfish	>8 yr 3 mo	16
106	*Lepisosteus osseus*	Longnose gar	24 yr	16
107			30 yr[2]	5
108	*Lepomis cyanellus*	Green sunfish	>7 yr 6 mo[3]	11
109			9 yr[2]	3
110	*Melanogrammus aeglefinus*	Haddock	15 yr[2]	16
111	*Micropterus salmoides*	Largemouth black bass	>11 yr[3]	11
112			16 yr[2]	25
113	*Osmerus mordax*	American smelt	6 yr[2]	31
114	*Perca fluviatilis*	European perch	>10 yr 8 mo	16
115			10 yr[2]	43
116	*Pleuronectes platessa*	European plaice	<30 yr[2]	16
117	*Polyodon spathula*	Paddlefish	24 yr[2]	45
118	*Pomoxis annularis*	White crappie	9 yr[2]	36
119	*P. nigromaculatus*	Black crappie	12 yr	11

/2/ In natural habitat. /3/ Still alive at time of report.

continued

30. LIFE SPANS: ANIMALS

Part I. VERTEBRATES

	Species	Common Name	Recorded Maximum Life Span	Reference
	(A)	(B)	(C)	(D)
	Pisces			
120	***Protopterus annectens***	West African lungfish	18 yr	11,16
121	***Salmo salar***	Atlantic salmon	13 yr[a]	16
122	***S. trutta***	Brown trout	10 yr	16
123	***Salvelinus namaycush***	Lake trout	12 yr	16
124			41 yr[a]	47
125	***Scomber scombrus***	Atlantic mackerel	3-4 yr	11
126			15 yr[a]	39
127	***Thunnus thynnus***	Bluefin tuna	7 yr[a]	42
	Chondrichthyes			
128	***Dasyatis pastinaca***	Stingray	>21 yr	16
129	***Raja maculata***	Skate	>5 yr 10 mo	16
	Agnatha			
130	***Lampetra fluviatilis***	River lamprey	<1 yr	11
131	***Petromyzon marinus***	Sea lamprey	7 yr[a]	51

/a/ In natural habitat.

Contributors: (a) Rockstein, Morris, (b) Cole, LaMont C., (c) Manville, Richard H., (d) Tanner, Vasco M., (e) Shaw, Charles E., (f) Carlander, Kenneth D., (g) Fitch, John E.

References: [1] Altman, P. L., and D. S. Dittmer, ed. 1962. Growth, including reproduction and morphological development. Federation of American Societies for Experimental Biology, Washington, D. C. [2] Anderson, A. W., ed. 1954. Com. Fisheries Rev. 16(9):28. [3] Bailey, R. M., and K. F. Lagler. 1938. Papers Mich. Acad. Sci. 23:577. [4] Bourlière, F. 1954. The natural history of mammals. Knopf, New York. [5] Breder, C. M., Jr. 1936. Bull. N. Y. Zool. Soc. 39:116. [6] Conant, R., and R. J. Hudson. 1949. Herpetologica 5:1. [7] Crandall, L. S. Unpublished. New York Zoological Society, N. Y., 1952. [8] Crossman, A. M. 1956. Copeia (1):54. [9] Farris, E. J. 1950. The care and breeding of laboratory animals. J. Wiley, New York. [10] Fleming, A. M. 1960. J. Fisheries Res. Board Can. 17:775. [11] Flower, S. S. 1925. Proc. Zool. Soc. London, p. 247. [12] Flower, S. S. 1925. Ibid., p. 269. [13] Flower, S. S. 1925. Ibid., p. 911. [14] Flower, S. S. 1925. Ibid., p. 1365. [15] Flower, S. S. 1931. Ibid., p. 145. [16] Flower, S. S. 1935. Ibid., p. 265. [17] Flower, S. S. 1936. Ibid. (2):369. [18] Flower, S. S. 1937. Ibid., p. 1. [19] Flower, S. S. 1938. Ibid., A, 108:195. [20] Flower, S. S. 1947. Ibid. 117:680. [21] Griffith, J. Q., and E. J. Farris. 1942. The rat in laboratory investigation. J. B. Lippincott, Philadelphia. [22] Gruneberg, H. 1943. Genetics of the mouse. Cambridge Univ. Press, London. [23] Haempel, A., and E. Neresheimer. 1914. Z. Fischerei 14(4):265. [24] Hart, J. L. 1931. Contrib. Can. Biol. Fisheries 6:429. [25] Hile, R. 1931. Indiana Lakes Streams Invest. 2:9. [26] Korschelt, E. 1922. Lebensdauer Altern und Tod. G. Fischer, Jena. [27] Lankester, E. R. 1870. On comparative longevity in man and the lower animals. Macmillan, London. [28] Laws, R. M. 1955. Zoo Life 10:41. [29] Lewis, W. M. 1950. Iowa State Coll. J. Sci. 24:287. [30] Low, S. H. Unpublished. U.S. Fish and Wildlife Service, Patuxent Research Refuge Records, 1952. [31] McKenzie, R. A. 1958. J. Fisheries Res. Board Can. 15:1313. [32] Mann, W. M. 1934. Wild animals in and out of the zoo. Smithsonian Institution, New York. p. 338. [33] Manville, R. H. 1957. J. Mammal. 38:279. [34] Manville, R. H. 1958. Ibid. 39:582. [35] Manville, R. H. Unpublished. Fish and Wildlife Service, U.S. Natl. Museum, Washington, D. C., 1961. [36] Miller, R. B. 1949. Preliminary biological surveys of Alberta watersheds, 1947-49. Alberta Dept. of Lands and Forests, Edmonton. [37] Miller, R. B., and W. A. Kennedy. 1948. J. Fisheries Res. Board Can. 7:176. [38] Mitchell, P. C. 1911. Proc. Zool. Soc. London, p. 425. [39] Nedelec, C. 1958. Rev. Trav. Inst. Pech. Marit. 22(2):121. [40] Palmer, R. S. 1954. The mammal guide. Doubleday, Garden City, New York. [41] Perkins, C. B. 1955. Copeia (3):262. [42] Schaefer, M. B., and J. C. Marr. 1948. U.S. Bur. Fisheries Bull. 51:187. [43] Seemann, W. 1961. Z. Fischerei, N.F. 9(7-10):603. [44] Shaw, C. E. 1957. Copeia (4):310. [45] Shields, J. T. 1958. S. Dakota Dept. Game Fish Parks Mimeo Rept. D.-J. F-1-R-7. [46] Snell, G. D. 1941. Biology of the laboratory mouse. Blakiston, Philadelphia. [47] Sprules, W. M. 1952. J. Fisheries Res. Board Can. 9:1. [48] Stebbins, R. C. 1948. Copeia (1):20. [49] Todd, T. W. 1939.

continued

30. LIFE SPANS: ANIMALS

Part I. VERTEBRATES

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Part II. INVERTEBRATES

	Class and Species	Common Name	Recorded Maximum Life Span	Reference
	(A)	(B)	(C)	(D)
	Chordata			
	Cephalochordata[1]			
1	*Branchiostoma lanceolatum*	Amphioxus	7 mo	6
	Ascidiacea			
2	*Ciona intestinalis*	Sea squirt	5 mo	11
	Echinodermata			
	Asteroidea			
3	*Asterias rubens*	Starfish	>5 yr	11
	Holothuroidea			
4	*Cucumaria planci*	Sea cucumber	>10 yr	11
	Arthropoda			
	Arachnida			
5	*Dermacentor andersoni*	Rocky Mountain wood tick	3-4 yr	7
6	*Tegenaria derhami*	Spider	4 yr	15
	Crustacea			
7	*Astacus fluviatilis*	Crayfish	30 yr	11
8	*Callinectes sapidus*	Blue crab	3 yr[3]	3
9	*Cyclops viridis*	Cyclops	10 mo[3]	20
10	*Daphnia magna*	Water flea	108 da	14
11	*Homarus gammarus*	European lobster	33 yr	9
	Insecta			
12	*Aedes geniculatus*	Mosquito	1 yr 6 mo	2
	Apis mellifera	Honeybee		
13		Queen	5 yr	11
14		Drone	6 mo	11
15		Worker	11 mo	11
16	*Cimex lectularius*	Bedbug (unfed)	6 mo	21
	Drosophila melanogaster	Fruit fly		
17		Normal	46 da	16
18		Vestigial	20 da	16
19	*Formica fusca*	Black ant (queen)	13 yr	11
20	*F. sanguinea*	Red ant (worker)	5 yr	11
21	*Lepisma saccharina*	Silverfish	2 yr	7
22	*Magicicada septendecim*	Periodical cicada	17 yr[3]	11
23	*Mantis religiosa*	Praying mantis	8 yr	13
24	*Melanoplus differentialis*	Differential grasshopper	3 mo	7
25	*Melolontha vulgaris*	June beetle (larva)	4-5 yr	11
26	*Musca domestica*	Housefly	76 da	9, 12
27	*Periplaneta americana*	American cockroach	4 yr 7 mo	8
	Insecta			
28	*Tribolium* spp.	Flour beetle	3 yr	7
	Symphyla			
29	*Scutigerella immaculata*	Garden symphylid	11-12 mo	7
	Annelida			
	Hirudinea			
30	*Hirudo medicinalis*	Medicinal leech	27 yr	9, 11
	Oligochaeta			
31	*Lumbricus terrestris*	Earthworm	6 yr	19
	Polychaeta			
32	*Nereis irrorata*	Clam worm	2 yr	5
	Mollusca			
	Cephalopoda			
33	*Loligo pealeii*	Squid	3-4 yr[3]	4
	Bivalvia			
34	*Mercenaria mercenaria*	Quahog	25-40 yr[2]	4
35	*Mytilus edulis*	Mussel	8-10 yr	4, 17
36	*Ostrea edulis*	Oyster	7-12 yr	17
37	*Pecten maximus*	Scallop	22 yr[3]	4
38	*Teredo navalis*	Shipworm	2 yr[3]	4
	Gastropoda			
39	*Acmaea dorsuosa*	Limpet	15 yr[3]	4
40	*Aplysia punctata*	Sea hare	1 yr[3]	4
41	*Doris* spp.	Sea lemon	1 yr	11
42	*Helix pomatia*	Land snail	18 yr[4]	11
43	*Littorina littorea*	Periwinkle	20 yr	4, 9
44	*Lymnaea* spp.	Freshwater snail	4-5 yr	11
	Polyplacophora			
45	*Ischnochiton magdalenensis*	Chiton	3-4 yr[3]	4
	Aschelminthes			
	Nematoda			
46	*Enterobius vermicularis*	Pinworm	2 mo	10
47	*Heterakis spumosa*	Rodent cecal worm	10 mo	18
48	*Loa loa*	African filarial worm	15 yr	18
49	*Necator americanus*	Hookworm	12 yr	18
50	*Rhabditis elegans*	Free-living roundworm	12 da	10
	Trichinella spiralis	Trichina worm		
51		Adults (in guinea pig)	5 wk	18
52		Cysts	30 yr	9

/1/ Subphylum. /2/ In natural habitat. /3/ Including developmental period. /4/ Still alive at time of report.

continued

30. LIFE SPANS: ANIMALS

Part II. INVERTEBRATES

	Class and Species	Common Name	Recorded Maximum Life Span	Reference
	(A)	(B)	(C)	(D)
	Aschelminthes			
53	Nematoda *Wuchereria bancrofti*	Bancroft's filarial worm (in man)	17 yr	18
54	Rotifera *Asplanchna sieboldi*	Rotifer	3 wk	10
	Platyhelminthes			
55	Cestoda *Diphyllobothrium latum*	Fish tapeworm (in man)	29 yr	18
56	*Moniezia expansa*	Sheep tapeworm	70 da	18
57	*Taenia saginata*	Beef tapeworm (in man)	35 yr	18
58	Turbellaria *Planaria torva*	Flatworm	1 yr 2 mo	9, 11
	Cnidaria			
59	Anthozoa *Actinia equina*	Sea anemone	15 yr	9
60	Hydrozoa *Hydra grisea*	Freshwater hydra	1-2 yr	11
	Porifera			
61	Demospongiae *Hippospongia* spp.	Commercial sponge	50 yr	10
62	Calcarea *Grantia capillosa*	Marine sponge	3 mo	11
	Protozoa			
63	Ciliata *Didinium nasutum*	Carnivorous ciliate (cysts)	10 yr	1

Contributors: (a) Cole, LaMont, C., (b) Rockstein, Morris, (c) Rehder, Harald A., (d) Hartman, Olga

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31. DEVELOPMENT AND LIFE SPANS: FOREST TREES, NORTH AMERICAN

For information on additional species, consult reference 1. Values are approximate, as great variation exists within species.

	Species	Common Name	Age at First Flowering yr	Trunk Diameter[1] at Maturity, ft		Height at Maturity, ft		Relative Growth Rate	Life Span[2] yr
				Average	Maximum	Average	Maximum		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
	Gymnospermae								
1	*Abies concolor*	White fir	30-40	3-4	6	120-150	200	Moderate	150-400
2	*Cupressus arizonica*	Arizona cypress	......	1-2.5	5	50-60	90	Slow	100-300
3	*Juniperus virginiana*	Eastern red cedar	10-15	1-2	4	40-50	100	Slow	150-300
4	*Larix occidentalis*	Western larch	20-40	3-4	8	140-180	210	Slow	300-600
5	*Picea glauca*	White spruce	10-15	1.5-2	4	60-70	120	Slow	150-350

/1/ Measurements at breast height (4.5 ft). /2/ Age at natural death.

continued

31. DEVELOPMENT AND LIFE SPANS: FOREST TREES, NORTH AMERICAN

	Species	Common Name	Age at First Flowering yr	Trunk Diameter[1] at Maturity, ft		Height at Maturity, ft		Relative Growth Rate	Life Span[2] yr
				Average	Maximum	Average	Maximum		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
	Gymnospermae								
6	*Pinus strobus*	Eastern white pine	10	2-4	6	80-120	220	Rapid	300-500
7	*Sequoia gigantea*	Giant sequoia	60	10-15	38	250-280	350	Rapid	2,000-3,000
8	*Taxodium distichum*	Bald cypress	......	2-5	12	80-120	150	Slow	600-1,200
9	*Taxus brevifolia*	Pacific yew	......	1-1.5	2	20-40	65	Slow	250-350
10	*Thuja occidentalis*	Northern white cedar	30	2-3	6	30-50	125	Slow	300-400
11	*Tsuga canadensis*	Eastern hemlock	30	2-3	6	60-80	160	Slow	300-600
	Angiospermae								
12	*Acer saccharinum*	Silver maple	......	2-3	7	60-80	120	Rapid	50-125
13	*Alnus rubra*	Red alder	10	1-3	5	80-100	130	Rapid	60-100
14	*Betula lenta*	Sweet birch	40	1-2	5	50-60	80	Moderate	150-250
15	*Carya illinoensis*	Pecan	10	2-4	6	90-120	180	Moderate	300
16	*Catalpa speciosa*	Northern catalpa	10	1-3	5	30-60	120	Rapid	100
17	*Cornus florida*	Flowering dogwood	5	0.5-1	1.5	20-40	50	Slow	125
18	*Fagus grandifolia*	American beech	40	1-3	4	70-100	120	Slow	300-400
19	*Fraxinus americana*	White ash	20	2-3	6	60-80	125	Rapid	260-300
20	*Ilex opaca*	American holly	5	1-2	4	40-50	140	Slow	100-150
21	*Juglans nigra*	Black walnut	12	2-3	7	50-90	150	Rapid	150-250
22	*Magnolia grandiflora*	Southern magnolia	......	2-3	4.5	60-80	135	Moderate	80-120
23	*Populus tremuloides*	Quaking aspen	5-20	1-2	4.5	40-60	120	Very rapid	70-100
24	*Prunus serotina*	Black cherry	10-15	1.5-3	5	50-60	100	Rapid	100-200
25	*Quercus alba*	White oak	20	2.5-4	8	80-100	150	Slow	300-600
26	*Salix nigra*	Black willow	10	1-2	6	30-40	120	Rapid	50-125
27	*Ulmus americana*	American elm	15	2-4	11	80-100	120	Rapid	150-300

/1/ Measurements at breast height (4.5 ft). /2/ Age at natural death.

Contributors: (a) Little, Elbert L., Jr., (b) Harrar, E. S.

References: [1] Altman, P. L., and D. S. Dittmer, ed. 1962. Growth, including reproduction and morphological development. Federation of American Socicties for Experimental Biology. Washington, D. C. [2] Collingwood, G. H., and W. D. Brush. 1947. Knowing your trees. American Forestry Association, Washington, D. C. [3] Harlow, W. M., and E. S. Harrar. 1958. Textbook of dendrology covering the important forest trees of the United States and Canada. Ed. 4. McGraw-Hill, New York. [4] Little, E. L., Jr. Unpublished. U. S. Dept. of Agriculture Forest Service, Washington, D. C., 1953. [5] Preston, R. J., Jr. 1948. North American trees (exclusive of Mexico and tropical United States). Iowa State College Press, Ames. [6] Righter, F. I. 1937. J. Forestry 37:935. [7] Sudworth, G. B. 1908. Forest trees of the Pacific slope. U.S. Dept. of Agriculture Forest Service, Washington, D. C. [8] U.S. Department of Agriculture Forest Service. 1948. U.S. Dept. Agr. Misc. Publ. 654.

32. LIFE SPANS: SEEDS

For information on additional species, consult reference 2, Part I.

Part I. IN AIR-DRY STORAGE

	Species	Common Name	Storage Conditions	Viability %		Life Span	Reference
				Initial	Final		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
1	*Abies procera*	Noble fir	-5°C	...	18	5 yr	14
2	*Acer saccharinum*	Silver maple	10°C; over water	...	95	6 mo	15
3	*Allium cepa*	Garden onion	5°-10°C; 6.4% moisture content; sealed	94	89	13 yr	8
4	*Avena sativa*	Common oat	20°-30°C	98	91	13 yr	10
5	*Capsicum frutescens*	Bush red pepper	5°C; 10.4% moisture content	73	74	6 yr	4

continued

32. LIFE SPANS: SEEDS

Part I. IN AIR-DRY STORAGE

	Species	Common Name	Storage Conditions	Viability % Initial	Viability % Final	Life Span	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
6	*Daucus carota*	Carrot	20°-30°C; 10.7% moisture content	67	52	6 yr	4
7	*Fraxinus pennsylvanica*	Green ash	5°C; 7.6% moisture content; sealed	68	39	8 yr	7
8	*Glycine soja*	Soybean	....	100	48	8 yr	17
9	*Gossypium* spp.	Cotton	7% moisture content; sealed	95	80	1 yr	11
10	*Hordeum vulgare*	Barley	....	100	76	10 yr	17
11	*Lactuca sativa*	Lettuce	0°C; 50% relative humidity	98	99	8 mo	13
12	*Lilium regale*	Regal lily	5°C; 4.5% moisture content; sealed	90	94	6 yr	6
13	*Lycopersicon esculentum*	Tomato	0°C; over $CaCl_2$	75	61	312 da	18
14	*Medicago sativa*	Alfalfa	23°C; 15% relative humidity	100	98	6.5 yr	1
15	*Nelumbium nelumbo*	Hindu lotus	....	...	...	150 yr	19
16	*Phaseolus vulgaris*	Kidney bean	23°C; 15% relative humidity	92	23	6 yr	1
17	*Phleum pratense*	Timothy	20°-30°C	97	56	10 yr	10
18	*Pinus caribaea*	Slash pine	5°C	78	49	7 yr	3
19	*Populus tremuloides*	Quaking aspen	20°-30°C	100	45	8 wk	16
20	*Prunus americana*	American plum	....	100	48	46 mo	12
21	*Solanum tuberosum*	Potato	0°C; sealed	45	87	12 yr	9
22	*Trifolium pratense*	Red clover	....	...	1	100 yr	19
23	*Triticum aestivum*	Wheat	....	100	91	10 yr	17
24	*Ulmus americana*	American elm	5°C; 7% moisture content; sealed	82	88	16 mo	5
25	*Zea mays*	Corn	....	92	79	9 yr	17

Contributor: Steinbauer, George P.

References: [1] Akamine, E. K. 1943. Hawaii Agr. Expt. Sta. Bull. 90. [2] Altman, P. L., and D. S. Dittmer, ed. 1962. Growth, including reproduction and morphological development. Federation of American Societies for Experimental Biology, Washington, D. C. [3] Barton, L. V. 1935. Contrib. Boyce Thompson Inst. 7:379. [4] Barton, L. V. 1939. Ibid. 10:205. [5] Barton, L. V. 1939. Ibid. 10:221. [6] Barton, L. B. 1939. Ibid. 10:399. [7] Barton, L. V. 1945. Ibid. 13:427. [8] Brown, E. 1939. Science 89:292. [9] Clark, C. F. 1940. Am. Potato J. 17:147. [10] Eastham, A. 1914. Agr. Gaz. Can. 1:634. [11] Flores, F. B. 1938. Philippine J. Agr. 9:347. [12] Giersbach, J., and W. Crocker. 1932. Contrib. Boyce Thompson Inst. 4:39. [13] Griffiths, A. E. 1942. Cornell Univ. Agr. Expt. Sta. Mem. 245. [14] Isaac, L. A. 1934. Ecology 15:216. [15] Jones, H. A. 1920. Botan. Gaz. 69:127. [16] Moss, E. H. 1938. Ibid. 99:529. [17] Robertson, D. W., and A. M. Lute. 1933. J. Agr. Res. 46:455. [18] San Pedro, A. V. 1936. Philippine Agriculturist 24:649. [19] Youngman, B. J. 1951. Kew Bull. Roy. Botan. Gardens, p. 423.

Part II. UNDISTURBED IN SOIL

For additional information on life spans of seeds buried in soil, consult reference 1. All seeds were buried at a depth of eight inches.

	Species	Common Name	Viability % Initial	Viability % Final	Life Span yr	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
1	*Avena fatua*	Wild oat	70	9	1	3,6
2	*Beta vulgaris*[1]	Beet	153	1	10	3,6
3	*Chrysanthemum leucanthemum*	Oxeye daisy	96	4	30	2
4	*Fraxinus americana*	White ash	50	4	6	3,6
5	*Helianthus annuus*	Common sunflower	100	44	1	2
6	*Medicago sativa*	Alfalfa	85	1	6	3,6
7	*Nelumbium nelumbo*[2]	Hindu lotus	...	...	1,040	4,5
8	*Nicotiana tabacum*	Common tobacco	89	13	30	3,6

/1/ Seed balls rather than seeds, which accounts for the 153% initial viability. /2/ In peat bed.

continued

32. LIFE SPANS: SEEDS

Part II. UNDISTURBED IN SOIL

	Species	Common Name	Viability % Initial	Viability % Final	Life Span yr	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
9	*Oenothera biennis*[3]	Common evening primrose	...	32	30	2,3,6
10	*Phleum pratense*	Timothy	...	1	21	3,6
11	*Poa pratensis*	Kentucky bluegrass	91	1	30	3,6
12	*Solanum nigrum*	Black nightshade	98	82	30	3,6
13	*Trifolium pratense*	Red clover	90	1	30	3,6

/3/ For additional data on seeds of this species buried for 70 years, consult reference 2.

Contributor: Steinbauer, George P.

References: [1] Crocker, W. 1938. Botan. Rev. 4:235. [2] Darlington, H. T. 1951. Am. J. Botany 38:379. [3] Duvel, J. W. T. 1905. U.S. Dept. Agr. Bur. Plant Ind. Bull. 83. [4] Libby, W. F. 1951. Science 114:291. [5] Ohga, I. 1926. Am. J. Botany 13:754. [6] Toole, E. H., and E. Brown. 1946. J. Agr. Res. 72:201.

Part III. AT VARIOUS TEMPERATURES

Seeds were stored in sealed containers. Median life span is number of years for 50% seed survival; maximum life span is for a single seed.

	Species	Common Name	Moisture Content[1] %	Life Span (Years) at 24°C Median	24°C Maximum	5°C Median	5°C Maximum	-4°C Median	-4°C Maximum	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
1	*Abies procera*	Noble fir	11	<1	1	1	>10	...	>16	9
2	*Allium cepa*	Garden onion	6	11	14	...	...	>20	>28	1,3,9,10
3	*Capsicum frutescens*	Bush red pepper	5	8	12	...	...	>20	>28	1,3,9,10
4	*Cinchona ledgeriana*	Ledger-bark cinchona	6	2	4	7	8	>9	>17	7,10
5	*Citrus limon*	Lemon	56	<1	<1	>1	>1	<1	<1	5
6	*Daucus carota*	Carrot	5	16	>20	...	...	>20	>28	1,3,9,10
7	*Fraxinus pennsylvanica*	Green ash	7	2	5	8	<9	...	...	6
8	*Gladiolus* spp.	Gladiolus	8	6	10	7	8	>10	>20	9,10
9	*Gossypium* spp.	Cotton	5	1	8	>13	>13	>13	>13	9
10	*Lactuca sativa*	Lettuce	4	13	15	...	...	>20	>28	1,3,9,10
11	*Lilium regale*	Regal lily	5	8	11	13	14	>17	>17	8,9
12	*Lycopersicon esculentum*	Tomato	5	17	>20	...	...	>20	>28	1,3,9,10
13	*Picea abies*	Norway spruce	5	...	...	...	...	17	>17	2,9
14	*Pinus caribaea*	Slash pine	Air-dry	4	8	8	>8	>10	>10	2,9
15	*Solanum melongena*	Eggplant	5	18	>20	...	...	>20	>28	1,3,9,10
16	*Ulmus americana*	American elm	7	2	4	8	10	15	>15	4,9

/1/ At time of storage.

Contributor: Barton, Lela V.

References: [1] Barton, L. V. 1935. Contrib. Boyce Thompson Inst. 7:323. [2] Barton, L. V. 1935. Ibid. 7:379. [3] Barton, L. V. 1939. Ibid. 10:205. [4] Barton, L. V. 1939. Ibid. 10:221. [5] Barton, L. V. 1943. Ibid. 13:47. [6] Barton, L. V. 1945. Ibid. 13:427. [7] Barton, L. V. 1947. Ibid. 15:1. [8] Barton, L. V. 1948. Boyce Thompson Inst. Plant Res. Professional Paper 2(6):45. [9] Barton, L. V. 1953. Contrib. Boyce Thompson Inst. 17:87. [10] Barton, L. V. Unpublished. Boyce Thompson Institute, Yonkers, N. Y., 1961.

33. LIFE SPANS: POLLEN

For information on additional species, consult reference 1. Lyophilized (columns C and D) = freeze-drying followed by storage in nitrogen in an otherwise uncontrolled environment. **Temp.** (column C): "17.5; 21" indicates that tests were conducted at temperatures averaging 17.5°C during the winter and 21°C during the summer. **Relative Humidity** (column D): 0 indicates lack of humidity due to storage over concentrated sulfuric acid in desiccator, unless otherwise specified; A = air; A-D = air-dry; Un = uncontrolled. **Viability** (column E) was based on germination tests made on artificial media at age given in column F.

	Species	Common Name	Storage Conditions		Viability %	Life Span da	Reference
			Temp. °C	Relative Humidity %			
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Gymnospermae						
1	*Ginkgo biloba*	Ginkgo	7	0[1]	35-45	730	30
2	*Picea abies*	Norway spruce	2	10-75	48	365	13
3	*Pinus strobus*	Eastern white pine	0-4	50[2]	91	413	7
4	*Tsuga canadensis*	Eastern hemlock	1-16	10-50	70-90	365	28
	Angiospermae (Monocotyledoneae)						
5	*Allium cepa*	Garden onion	Lyophilized		22	191	15
6	*Gladiolus hybrida*	Hybrid gladiolus	10	50	30	102[3]	23
7	*Hordeum vulgare*	Barley	2.2[4]	....	9.5-40.5	19-26[5]	27
8	*Iris graminea*	Grass iris	17.5; 21	0	....	57	26
9	*Lilium regale*	Regal lily	-20	A-D	65	161	25
10	*Phoenix dactylifera*	Date palm	-13[6]	....	60-70	365[5]	6
11	*Poa compressa*	Canada bluegrass	17.5; 21	0-90	....	1	26
12	*Tradescantia virginiana*	Virginia spiderwort	17.5; 21	0	....	40	26
13	*Triticum aestivum*	Wheat	16-18	Humid	....	0.5	8
14	*Zea mays*	Corn	5-10	50-80	70	3[5]	17
	Angiospermae (Dicotyledoneae)						
15	*Acer* sp.	Maple	17-22	A-D	....	18	12
16	*Alnus glutinosa*	European alder	17.5; 21	0	....	53	26
17	*Antirrhinum majus*	Snapdragon	10-22	....	Poor	670	17
18	*Betula lutea*	Yellow birch	Room	25	3	30	13
19	*Carya illinoensis*	Pecan	5	Moist	40	4	33
20	*Cinchona ledgeriana*	Ledger-bark cinchona	10	35-50	5-10	365	24
21	*Citrus* sp.	Citrus	2	25	63	550	16
22	*Cornus mas*	Cornelian cherry dogwood	17.5; 21	30	....	74	26
23	*Cucumis melo*	Muskmelon	-18	....	98	30	9
24	*Cucurbita moschata*	Cushaw	-17	Un	98	30[5]	10
25	*Digitalis purpurea*	Common foxglove	0-4	0	....	172	26
26	*Fagus sylvatica*	European beech	24	A-D	....	41	18
27	*Fragaria* spp.	Strawberry	24	A-D	....	>16	5
28	*Gossypium barbadense*	Pima cotton	4.4-10.0	....	64	4[6]	11
29	*Ipomoea batatas*	Sweet potato	Lyophilized		76[7]	354	15
30	*Juglans sieboldiana*	Siebold walnut	0	40-60	12	253	4
31	*Lycopersicon esculentum*	Tomato	-190	....	....	1,095	31
32	*Malus pumila*	Common apple	2-8	50	20	1,460	20
33	*Medicago sativa*	Alfalfa	Room	0[1]	....	180[5]	2
34	*Nicotiana sylvestris*	Tobacco	17-22	....	....	205[8]	12
35	*Oenothera biennis*	Common evening primrose	17.5; 21	A; 30	....	8	26
36	*Persea americana*[9]	American avocado	15	0[1]	....	153	29
37	*Pisum sativum*	Garden pea	-5	35	....	450	32
38	*Populus suaveolens*	Mongolian poplar	-3 to +3	A-D	....	45	3
39	*Prunus amygdalus*	Almond	-18	....	24	1,130	9
40	*P. domestica*	Garden plum	2-8	50	20	1,278	20
41	*P. persica*	Peach	2-8	50	1-20	1,095	20
42	*Pyrus communis*	Pear	2-8	50	20	1,278	20
43	*Quercus coccinea*	Scarlet oak	2	25-35	46	365	13
44	*Rhododendron* spp.	Rhododendron	-190	....	....	730-1,095	31
45	*Ribes glutinosum*	Nutmeg currant	17-22	0-27.2	....	117	12
46	*Salix gracistyla*	Big catkin willow	10	A-D	1	105	21
47	*Solanum tuberosum*	Potato	-30 to -20	Un	....	365[6]	14

/1/ Storage over calcium chloride in desiccator. /2/ Humidified, at 75% relative humidity and 4°C, for 12 hours after storage. /3/ Data recorded on the basis of seed set per capsule. /4/ Flower spike or flower cut in early morning and kept under refrigeration. /5/ Data recorded on the basis of seed or fruit set. /6/ Pollen mixed with diluent and then stored in sealed or stoppered vials. /7/ Peroxidase test. /8/ Pollen sealed in ampules with CO_2 and stored under reduced pressure. /9/ Horticultural varieties.

continued

33. LIFE SPANS: POLLEN

	Species	Common Name	Storage Conditions: Temp. °C	Storage Conditions: Relative Humidity %	Viability %	Life Span da	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Angiospermae (Dicotyledoneae)						
48	*Trifolium hybridum*	Alsike clover	24	A-D	....	12	19
49	*Vicia faba*	Broad bean	17.5; 21	0	....	21	26
50	*Vitis* spp.[9]	Grape	-12	28	21	1,460	22

/9/ Horticultural varieties.

Contributors: (a) Pfeiffer, Norma E., (b) Hesse, Claron O.

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34. GROWTH RATES: PLANT TISSUES

Nutrient fluids used in plant tissue cultures are chiefly composed of chemicals. **Culture Medium** (column C): GA = Gautheret's agar; CM = coconut milk (liquid endosperm of *Cocos nucifera*); IAA = indoleacetic acid; HA = Hildebrandt's agar; WL = White's liquid; WA = White's agar; WAS = modified White's agar for sunflower tissues; HAS = modified Hildebrandt's agar for sunflower tissues; WAT = modified White's agar for tobacco tissues; BL = Bonner's liquid; BNA = Burkholder-Nickell agar. **Relative Increase** (column F): W_1/W_0 = final weight divided by initial weight. **Relative Growth Rate** (column G): r = instantaneous growth rate expressed as percent increase/day.

	Species (Common Name)	Tissue	Culture Medium	Growth Period da	Initial Weight mg	Relative Increase W_1/W_0	Relative Growth Rate 100 r	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
1	*Amorphophallus rivieri* (devil's-tongue)	Tuber	GA + 15% CM	30	250	8	6.92	13
2	*Brassica campestris*	Root	GA	60	100	4.1	2.35[1]	6
3	(bird rape)		GA + 0.3 mg/liter IAA	60	100	5.6	2.87	

/1/ Growth had ceased by fourth subculture, but tissue survived for another year.

continued

34. GROWTH RATES: PLANT TISSUES

	Species (Common Name)	Tissue	Culture Medium	Growth Period da	Initial Weight mg	Relative Increase W_1/W_0	Relative Growth Rate 100 r	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
4	***Chrysanthemum frutescens*** (marguerite chrysanthemum)	Crown gall	HA	42	35	3.71	3.12	9
5	***Cichorium intybus*** (chicory)	Tuber	GA	60	100	3.7	2.18	6
6			GA + 0.3 mg/liter IAA	60	100	5.9	2.96	
7	***Daucus carota*** (carrot)	Root	WL	21	15	11.1	11.4	12
8		Root cambium	GA + 0.1 mg/liter IAA	18	125	3.56	7.04	4
9				304	0.5	300,000	4.14	5
10				0-7	170	2	9.9	7
11				7-15	340	1.61	6	7
12				15-21	548	1.72	9	7
13				21-41	941	1.97	3.3	7
14				41-67	1,852	2.13	2.7	7
15				67	170	20.32	4.5	7
16		Vascular cambium	GA	60	100	5	2.68	6
17			GA + 0.3 mg/liter IAA	60	100	7.1	3.26	
18		Root phloem	WL + 15% CM	0-2	3.98	1.15	7	2
19				2-4	4.6	1.2	9.1	
20				4-6	5.55	1.58	22.9	
21				6-8	8.75	1.72	27.1	
22				8-10	15.05	1.98	34.2	
23				10-12	29.8	1.9	32.1	
24				12-14	56.6	1.63	22.4	
25				14-16	92.15	1.56	22.2	
26				16-20	139	1.41	8.6	
27				20-24	196.9	1.19	4.3	
28				24	3.98	59	16.98	
29	***Helianthus annuus*** (common sunflower)	Crown gall[2]	WA[3]	42	25	15.6	6.54	10
30			WA	42	25	5.2	3.92	10
31			WAS	42	25	13.6	6.21	10
32			HAS[4]	42	25	80	10.41	20
33	***H. tuberosus*** (Jerusalem artichoke sunflower)	Tuber	GA	60	100	1.95[5]	1.11	6
34			GA + 0.3 mg/liter IAA	60	100	5.4	2.81	6
35			GA	35	283	1.08	0.22	3
36			GA + 0.3 mg/liter IAA	35	247	1.86	1.77	3
37			GA + 100% CM	35	237	4.36	4.21	3
38			GA + 25% CM	35	245	3.03	3.17	3
39		Crown gall[2]	GA	60	100	5.1	2.72	6
40			GA + 0.3 mg/liter IAA	60	100	4.5	2.51	
41	***Nicotiana glauca* x *N. langsdorffii***[6] (tobacco)	Stem	WA	35	19.1	6.1	5.17	1
42				42	6.8	14.2	6.32	
43			WAT	42	25	4.84	3.75	11
44				42	25	7.80	4.89	
45	***Pisum sativum*** (garden pea)	Root callus	BL + 1 g/liter yeast extract + 1×10^{-6} *M* 2,4-D	56	90	10.9	4.26	23
46	***Rosa*** sp. (rose)	Stem	WL + 6 mg/liter 2,4-D + 0.1% each yeast and malt extracts	14	.....	19.9	19.3	18
47	***Rumex acetosa*** (garden sorrel)	Root tumor[7]	BNA + 0.4 mg/liter thiamine	21	.....	12	11.8	16
48			BNA	25-34	.....	6.0	19.9	17
49				40	.....	16	6.92	
50			BNA + 30% CM	21	.....	11.1	11.5	15
51	***Scorzonera hispanica*** (black salsify serpentroot)	Root	GA	60	100	2.53	1.57	8
52			GA + 1.0 mg/liter IAA	60	100	10.86	3.98	
53		Crown gall[2]	GA	60	100	8.85	3.63	8
54			GA + 1.0 mg/liter IAA	60	100	9.20	3.70	
55	***Solanum tuberosum*** (potato)	Tuber	WA + 6% CM and 18 mg/liter 2,4-D	35	3	54.7	11.4	21
56	***Tagetes erecta*** (Aztec marigold)	Stem	HAS	35	20	55	11.44	14
57		Crown gall	HAS	42	35	25	7.65	9
58			HAS + 0.5% dulcitol	42	35	28.7	7.98	
59			HAS + 0.5% methanol	42	35	30.6	8.14	

/2/ Free from inducing microorganism *(Agrobacterium tumefaciens)*. /3/ Optimal growth at sucrose concentration of 1% at pH 5, 26°C. /4/ Nitrate present as optimum of 0.016 *M* instead of 0.0038 *M*. /5/ Growth during first subculture; dead after third subculture. /6/ One of a number of tobacco hybrids forming spontaneous tumors at certain stages of development. /7/ Wound tumor disease of sorrel and other plants, resulting from infection by *Aureogenus magnivena*.

continued

34. GROWTH RATES: PLANT TISSUES

	Species (Common Name)	Tissue	Culture Medium	Growth Period da	Initial Weight mg	Relative Increase W_1/W_0	Relative Growth Rate 100 r	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
60	*Taxus brevifolia* (Pacific yew)	Pollen	WA + 15% CM and 0.6 ppm 2,4-D	28		3	3.92	24
61	*Vinca rosea* (Madagascar periwinkle)	Crown gall	HA	42	35	12.7	6.05	9
62	*Vitis vinifera* (European grape)	Stem	HA[8]	42	30	40	8.78	19
63		Gall[9]		42	30	30	8.10	
64	*Zea mays* (corn)	Endosperm	WA + 1.5 x 10^{-2} *M* asparagine	25	120	3.6	5.12	22

/8/ Plus 3.0 g/liter casein hydrolysate, 0.1 mg/liter each NAA and kinetin, 40 mg/liter adenine. /9/ Induced by *Phylloxera vestatrix*.

Contributor: Caplin, Samuel M.

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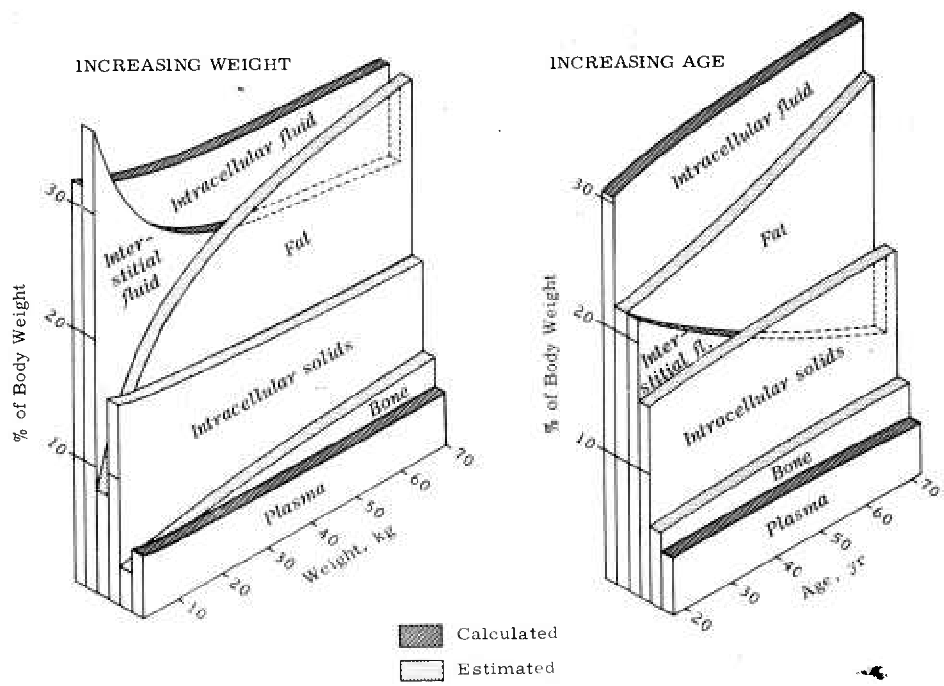
IV. MORPHOLOGY

35. BODY COMPOSITION WITH INCREASING WEIGHT AND AGE: MAN

Method of determination: ***Interstitial fluid*** calculated by subtracting plasma volume from thiocyanate diffusion space.[1] ***Intracellular fluid*** calculated by subtracting thiocyanate diffusion space[1] from total body water. ***Intercellular solids***[2] estimated by the method of McCance [2] (intracellular water = 67% intracellular mass). ***Bone***[2] estimated from the data of Iob and Swanson [1], Mitchell [3], Shohl [4], and Widdowson [5]. ***Fat***[2] estimated by difference between total body weight and all other components.



/1/ The use of thiocyanate diffusion space as a measure of extracellular fluid is based on the probability that in normal persons the thiocyanate and other similar diffusion spaces are in fairly constant proportion in that nebulous entity, extracellular fluid, and that therefore the rate of change of the curves should not vary (although the absolute values may). /2/ Because of the lack of data, values indicate order of magnitude only.

Contributors: Henschel, Austin; Bass, David E.; and Wedgwood, Ralph J.

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36. BODY SURFACE AREA: MAMMALS

Part I. SURFACE AREA FOR KNOWN WEIGHT AND HEIGHT: MAN

Values are square meters of body surface area and were derived by the Sendroy and Cecchini method.

	Height cm	Weight, kg 5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
1	20	0.18																		
2	30	0.20	0.35																	
3	40	0.23	0.36																	
4	50	0.26	0.38																	
5	60	0.29	0.41	0.54																
6	70	0.33	0.44	0.57																
7	80	0.37	0.48	0.60	0.68															
8	90	0.42	0.52	0.63	0.72	0.80														
9	100	0.48	0.57	0.67	0.76	0.84	0.92													
10	110	0.55	0.64	0.72	0.80	0.88	0.96	1.04	1.11											
11	120	0.62	0.69	0.77	0.85	0.93	1.01	1.08	1.15	1.23	1.30	1.37	1.44							
12	130		0.76	0.83	0.91	0.98	1.05	1.12	1.20	1.27	1.34	1.42	1.48	1.54	1.61	1.68	1.74	1.81	1.87	
13	140			0.89	0.97	1.03	1.10	1.17	1.25	1.32	1.39	1.46	1.52	1.58	1.65	1.72	1.78	1.84	1.90	1.97
14	150				1.03	1.09	1.16	1.23	1.30	1.37	1.44	1.50	1.57	1.63	1.70	1.76	1.82	1.88	1.94	2.01
15	160					1.15	1.22	1.29	1.36	1.43	1.49	1.55	1.62	1.68	1.75	1.81	1.86	1.92	1.98	2.05
16	170						1.28	1.35	1.42	1.48	1.54	1.61	1.67	1.73	1.80	1.86	1.91	1.97	2.03	2.09
17	180							1.42	1.48	1.54	1.60	1.67	1.73	1.79	1.85	1.91	1.96	2.02	2.08	2.14
18	190								1.55	1.61	1.67	1.73	1.79	1.85	1.91	1.96	2.02	2.07	2.13	2.18
19	200										1.74	1.80	1.85	1.91	1.96	2.02	2.07	2.13	2.18	2.24
20	210												1.92	1.97	2.02	2.07	2.13	2.18	2.24	2.30
21	220														2.08	2.13	2.18	2.24	2.30	2.36
22	230																2.25	2.31	2.36	2.42
23	240																			2.48

	Height cm	Weight, kg 100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185
13	140	2.03	2.10	2.17	2.23														
14	150	2.07	2.14	2.21	2.27	2.33	2.39	2.44	2.50	2.55	2.61	2.66	2.72	2.77					
15	160	2.12	2.18	2.24	2.30	2.36	2.42	2.47	2.53	2.58	2.63	2.69	2.74	2.80	2.86	2.91	2.96	3.01	3.06
16	170	2.16	2.22	2.28	2.33	2.39	2.45	2.51	2.56	2.62	2.67	2.73	2.78	2.83	2.89	2.94	2.99	3.04	3.09
17	180	2.20	2.26	2.32	2.38	2.43	2.49	2.54	2.60	2.66	2.71	2.77	2.83	2.88	2.93	2.98	3.03	3.08	
18	190	2.24	2.31	2.36	2.42	2.48	2.53	2.59	2.64	2.70	2.75	2.81	2.87	2.92	2.97	3.03	3.08		
19	200	2.30	2.35	2.41	2.47	2.53	2.58	2.63	2.69	2.74	2.80	2.86	2.92	2.97	3.02	3.07			
20	210	2.35	2.41	2.47	2.53	2.58	2.63	2.68	2.74	2.80	2.86	2.92	2.97	3.02	3.07				
21	220	2.41	2.47	2.53	2.58	2.63	2.69	2.75	2.81	2.87	2.92	2.97	3.03	3.08					
22	230	2.47	2.53	2.58	2.64	2.70	2.76	2.82	2.87	2.93	2.98	3.03	3.08						
23	240	2.54	2.60	2.65	2.71	2.77	2.83	2.88	2.93	2.98	3.04	3.09							
24	250			2.73	2.78	2.84	2.90	2.95	3.00	3.06									
25	260					2.93	2.97	3.02	3.08										

Contributor: Sendroy, Julius, Jr.

Reference: Sendroy, J., Jr., and L. P. Cecchini. 1954. J. Appl. Physiol. 7:1.

Part II. CONSTANTS FOR USE IN SURFACE AREA FORMULA: MAMMALS

K-values were derived from surface area values taken from extensive literature sources, using the formula $K = \frac{\text{area (sq cm)}}{\text{weight } 2/3 \text{ (g)}}$. Method (column D): P = perimeter; S = skinning; T = triangulation; M = mold; C = paper cover; I = surface integrator. Values in parentheses are ranges, estimate "c" for body weight (column E) and "d" for K-value (column F) (cf. Introduction).

	Species	Common Name	Subjects no.	Method	Body Weight g	K-Value Constant	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
1	*Balaenoptera physalus*	Finback whale	3	P	160,000(115,000-220,000)	8.3(7.5-8.9)	19
2			1	P	43,000,000	11.1	19

continued

36. BODY SURFACE AREA: MAMMALS

Part II. CONSTANTS FOR USE IN SURFACE AREA FORMULA: MAMMALS

Species	Common Name	Subjects no.	Method	Body Weight g	K-Value Constant	Reference
(A)	(B)	(C)	(D)	(E)	(F)	(G)
Bos taurus (Hereford-Shorthorn)	Cattle	15	S	476,000(208,000-762,000)	9.3(8.1-10.8)	25
		15[1]	S	375,000(163,000-641,000)	11.0(9.0-13.8)	25
		10[1,2]	S	241,000(89,000-407,000)	9.9(9.3-10.5)	28
		11[1,3]	S	315,000(78,000-493,000)	9.4(8.8-10.0)	28
		7[1,4]	S	695,000(476,000-815,000)	7.6(7.3-7.9)	28
Canis familiaris	Dog	6	S	1,070(130-3,650)	10.1(9.3-11.0)	27
		1	S	1,080	11.0	10
		8	S & P	12,700(3,200-29,800)	11.6(10.2-12.5)	23
		2	T	9,500(8,900-10,100)	9.9(9.85-9.90)	6
		7	M	14,310(3,390-32,640)	11.2(10.3-12.1)	5
		1	C	27,000	12.3	12
Capra hircus	Goat	1	T	15,100	10.5	6
Cavia spp.	Guinea pig	6	S	206(123-269)	9.5(8.4-10.8)	21
		3	S	157(123-191)	10.4(10.1-10.8)	21
		3	S	256(235-269)	8.6(8.4-8.9)	21
		3	S	373(148-650)	9.6(9.0-9.9)	8
		13[5]	S	323(160-810)	8.9(7.9-9.6)	14
		2	T	400(380-420)	7.1	6
Didelphis sp.	Opossum	4	S	1,200(100-1,300)	11.3(10.5-11.8)	11
Equus caballus	Horse	8	S	(47,000-555,000)	10.5	26
		11	I	(70,000-750,000)	(8.2-10.3)	3
Erinaceus europaeus	European hedgehog	1	S	200	7.5	10
Felis catus	Cat	3	S	708(219-1,389)	10.7(9.5-11.9)	27
		2	S	100(84-116)	10.0(9.9-10.0)	27
		2	T	1,550(1,500-1,600)	8.7(8.6-8.9)	6
Macaca mulatta	Rhesus monkey	6	M	2,670(800-6,600)	11.8(10.8-13.2)	2
Mus musculus (albino)	House mouse	12	S	16(10-22)	11.4(9.7-13.3)	21
		11	S	15(6-27)	7.9	9
		3	S	16(11-20)	10.5(10.4-10.5)	8
		64[5]	S	13	6.9	21,24
		13	M	(16-25)	9.0(8.4-9 [illegible]	[illegible]
Myotis lucifugus	Little brown bat	2	S	8.3(5.0-11.6)	44.5(44.0 [illegible]	[illegible]
Oryctolagus cuniculus	European rabbit	3[6]	S	32(26-40)	8.5	[illegible]
		3[6]	S	560(70-925)	9.7	9
		2	T	1,130(1,120-1,140)	10.0(9.0-11.0)	6
Ovis aries	Sheep	8	S	(21,800-29,100)	10.7	16
		15	S	(3,780-50,400)	9.1	16
		14	S	(23,600-37,700)	8.5	18
		115	I	(2,200-68,000)	8.3	22
Rattus norvegicus (albino)	Norway rat	62	S	176(25-461)	11.4(9.6-13.0)	4
		22	S	197(65-335)	10.5(9.0-12.7)	17
		14	S	133(70-310)	11.6(10.9-12.1)	2
		5	S	80(50-129)	9.9(9.6-10.4)	13
		5	S	42(35-53)	10.5(10.1-10.8)	2
		2	T	170(164-177)	7.15	6
		72	M	(19-418)	9.0	15
		56	M	125(24-366)	7.5(6.6-8.3)	7
		14[5]	M	95(22-164)	7.6(7.3-8.8)	7
Sorex cinereus	Gray shrew	1	S	3.5	8.0	20
Sus scrofa	Swine	7	S	48,300(1,100-123,000)	9.9(8.6-12.4)	25
		16	I	(25,000-330,000)	9.0	3
		1	T	40,110	15.3	6

/1/ Empty weight. /2/ Thin. /3/ Medium. /4/ Fat. /5/ Starved. /6/ Surface area of one side of ear only.

Contributors: Morrison, Peter R., and Meyer, Marion P.

References: [1] Benedict, F. G. 1932. Yale J. Biol. Med. 4:385. [2] Benedict, F. G. 1934. Ergeb. Physiol. Exptl. Pharmakol. 36:300. [3] Brody, S., J. E. Comfort, and J. S. Matthews. 1928. Missouri Univ. Agr. Expt. Sta. Bull. 115. [4] Carman, G. G., and H. H. Mitchell. 1926. Am. J. Physiol. 76:380. [5] Cowgill, G. R., and D. L. Drabkin. 1927. Ibid. 81:36. [6] Custor, J. 1873. Arch. Anat. Physiol., Physiol. Abt., p. 478. [7] Diack, S. L. 1930. J. Nutr. 3:289. [8] Dreyer, G., and W. Ray. 1912. Phil. Trans. Roy. Soc. London, B, 202:191. [9] Giaja, J.

continued

Part II. CONSTANTS FOR USE IN SURFACE AREA FORMULA: MAMMALS

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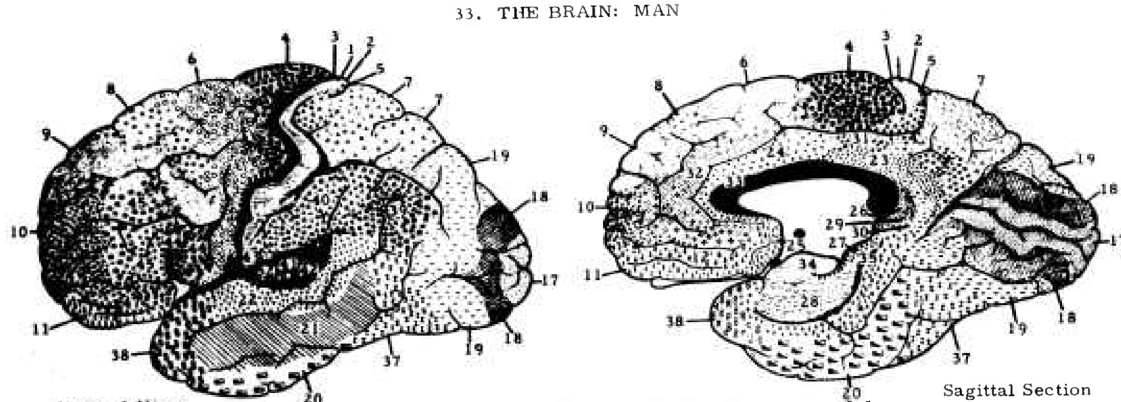
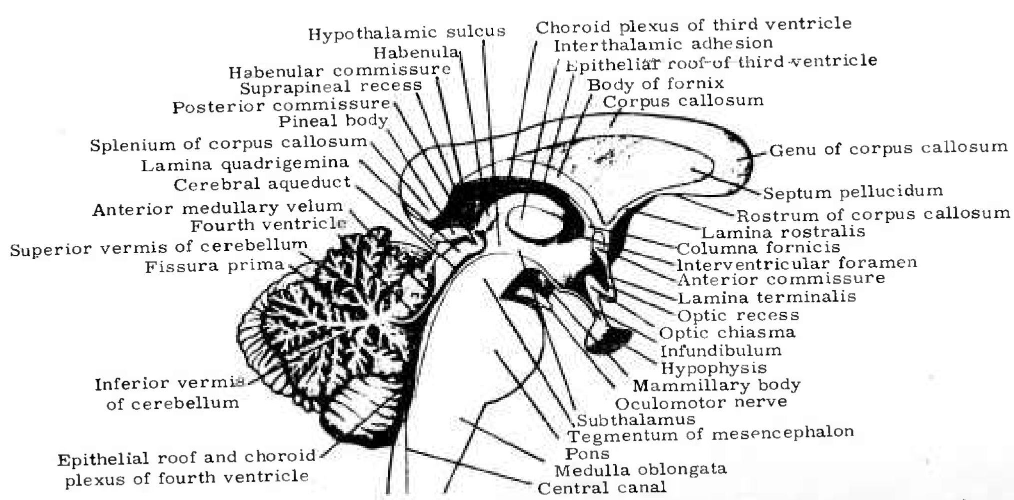
33. THE BRAIN: MAN



Map of the Cytoarchitectonic Areas of the Cerebral Cortex [1]
(Numbers indicate areas of Brodmann)



Midsagittal Section through Brain Stem [2]

continued

37. BRAIN: MAN

Contributors: (a) von Bonin, Gerhardt, (b) Bartelmez, George W.

References: [1] Bailey, P., and G. von Bonin. 1951. The isocortex of man. Univ. Illinois Press, Urbana.
[2] Ranson, S. W., and S. L. Clark. 1959. The anatomy of the nervous system. Ed. 10. W. B. Saunders, Philadelphia.

Part I. REGIONS AND FUNCTIONS

		Region (A)	General Functions (B)	Sub-regions (C)	Specific Functions (D)
	PROSENCEPHALON	Telencephalon			
1		Cerebral cortex	Highest level of integration; symbolism, memory, forecasting	Prefrontal, frontal, parietal, occipital, temporal	Association: autonomic, general motor, sensory, visual, auditory.
2		Rhinencephalon	Olfaction, "visceral brain," emotion	Olfactory bulb, cortex; amygdala; limbic cortex of hippocampus; fornix; mammillary body	Association: autonomic-visceral integration; olfaction.
3		Corpus striatum	Smoothing of motor behavior; inhibition of posture, movement patterns, extrapyramidal relay	Caudate nucleus, putamen, globus pallidus	Motor relay (globus pallidus) back to cortex into thalamus.
		Diencephalon			
4		Epithalamus	"Drive"	Habenular nucleus	
5		Thalamus	Sensory relay to cortex; thalamocortical circuits	Anterior, midline, medial, lateral, posterior, pulvinar, ventral	Cortical relay nuclei: anterior, emotion (?); medial and ventral, sensory; pulvinar, gnostic and practic. Unspecific intralaminar nuclei. Basal ganglia relay ventrolateral.
6		Metathalamus		Medial, lateral geniculate	Medial: acoustic to supratemporal plane. Lateral: visual to striate area.
7		Subthalamus	Motor, extrapyramidal	Subthalamic nucleus	Integrative facilitation and inhibition.
8		Hypothalamus	Principal forebrain center for integration of visceral functions involving autonomic nervous system[1]	Anterior, middle, lateral, posterior	Generally anterior part, trophotropic (parasympathetic); posterior part, ergotropic (orthosympathetic).
9	MESENCEPHALON		Postural reflexes; nuclei for cranial nerves	Superior colliculus, inferior colliculus, substantia nigra, red nucleus, tegmentum, reticular formation (part of), basis pedunculi, nucleus nerves III, IV, V (part of)	Relay for visual reflexes (protective), auditory reflexes, extrapyramidal junction of striatal and cortical influences; contributes to righting reflexes, tracts; facilitatory and inhibitory influences on motor performance.
	RHOMBENCEPHALON	Metencephalon			
10		Cerebellum	Maintenance of posture; equilibrium; coordination, smoothing of complex movements	Corpus cerebelli, anterior and posterior lobe; flocculonodular lobe	Paleocerebellum: equilibration, maintenance of posture. Neocerebellum: postural reflexes, stabilizing, smoothing more complex movements initiated in cortex, facilitation of posture change.
11		Pons		Pontine nucleus, reticular formation, cerebellar peduncles, tracts, nucleus nerve V (part of)	Relay between cerebro-cerebellar, motor inhibitory areas.
		Myelencephalon			
12		Medulla oblongata	Reflex center for cardiac vasomotor, vomiting, deglutition, respiratory, gustatory, facial reflexes	Nucleus nerves V (part of), IX, XI, XII; inferior olivary; tracts; reticular nuclei of medullary tegmentum	Posture.

/1/ Energy and water exchange, sexual function, sleep, vasomotor.

continued

37. BRAIN: MAN

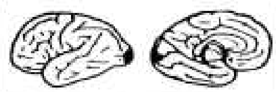
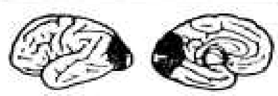
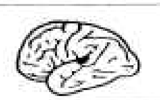
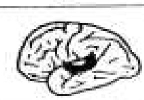
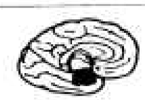
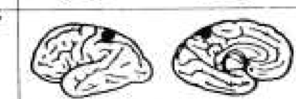
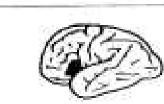
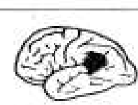
Part I. REGIONS AND FUNCTIONS

Contributors: (a) Stevenson, James A. F., (b) von Bonin, Gerhardt

References: [1] Barr, M. L. Unpublished. Univ. Western Ontario Dept. of Anatomy, London, Canada, 1953. [2] Fulton, J. F. 1949. Physiology of the nervous system. Ed. 3. Oxford Univ. Press, New York. [3] Ranson, S. W., and S. L. Clark. 1959. The anatomy of the nervous system. Ed. 10. W. B. Saunders, Philadelphia.

Part II. CORTICAL CEREBRAL REGIONS AND FUNCTIONS

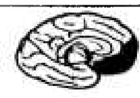
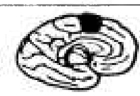
Area (column C): numbers indicate areas of Brodmann.

	Gross Region	Location	Area	Principal Connected Pathways and Areas	Function
	(A)	(B)	(C)	(D)	(E)
1	Occipital (striate cortex)		17	Optic radiation; lateral geniculate body of the thalamus; optic tract; chiasm; optic nerve; retina	Vision
2	Occipital (parastriate) and parietal (preoccipital)		18,19	Superior colliculus of brain stem; areas 37, 8, 23, 21 of Brodmann; opposite hemisphere (areas 18, 19)	Visual elaboration
3	Temporal (Heschl's gyrus)		41	Auditory radiation; medial geniculate body; inferior colliculus; nucleus of lateral lemniscus; superior olive; dorsal and ventral cochlear nucleus in brain stem; cochlear nerve; spiral ganglion; hair cells in organ of Corti	Hearing (auditosensory)
4	Temporal		42,22		Hearing (auditopsychic)
5	Temporal (piriform area)		28,34	Lateral root; olfactory tract; olfactory bulb; fila olfactoria	Olfaction
6	Parietal (post central convolution)		3,1,2	Connected through posteroventral nuclei with mesial and trigeminal fillets and spinothalamic tract; dorsal root; sensory root ganglion; peripheral sensory nerves	Somatic sensation
7	Parietal (superior lobule)		5,7a	Dorsolateral thalamus; association fibers connecting areas 1, 44, 19, 8, 46 of Brodmann	Sensory elaboration (motor skills)
8	Frontal (pons triangularis and opercularis); dominant hemisphere; Broca's area		44,45	Receives afferents from area 3 of Brodmann; sends impulses to areas 4 and 5	Speech (motor)
9	Parietal (lower lobule); dominant hemisphere; Wernicke's area		40,39	Association fibers connecting areas 1, 42, 19 of Brodmann	Speech (sensory) (Gnosia)

continued

37. BRAIN: MAN

Part II. CORTICAL CEREBRAL REGIONS AND FUNCTIONS

	Gross Region	Location	Area	Principal Connected Pathways and Areas	Function
	(A)	(B)	(C)	(D)	(E)
10	Temporal		21,22	Frontal and parietal association areas (areas 11, 12, 13, 39, 40 of Brodmann)	Memory
11	Frontal	 	9,10,11, 12,13, 14,24	Orbitofrontal cortex (areas 9,10,11,12 of Brodmann) and posterior and medial orbital gyri (areas 13 and 14 of Walker) are connected to dorsomedial nuclei of thalamus which has hypothalamic connections; the anterior cingulate gyrus (area 24) is projection area of anterior nuclei of thalamus	Projection of conscious thought
12	Frontal (precentral area, motor and premotor)	 	4,6	Internal capsule, pyramidal decussation, corticospinal tracts, anterior horn cells, motor roots; connected by way of lateroventral nucleus and the superior cerebellar peduncle with spinocerebellar afferents	Motion (motor activity)

Contributor: Raaf, John

References: [1] Fulton, J. F. 1949. Physiology of the nervous system. Ed. 3. Oxford Univ. Press, New York. p. 370. [2] Kluver, H., and P. Bucy. 1939. Arch. Neurol. Psychiat. 42:979. [3] Penfield, W., and T. Rasmussen. 1950. The cerebral cortex of man. Macmillan, New York. [4] Ranson, S. W., and S. L. Clark. 1959. The anatomy of the nervous system. Ed. 10. W. B. Saunders, Philadelphia. [5] Spiegel, E. A. 1934. Arch. Neurol. Psychiat. 31:469. [6] von Bonin, G. 1950. Essay on the cerebral cortex. C. C. Thomas, Springfield, Ill.

Part III. NUCLEI OF METATHALAMUS AND DORSAL THALAMUS

Function (column B): A = associational; D = diffuse associational; I = internal relay; E = external relay; U = unclassified or doubtful.

	Nucleus	Function	Afferents	Efferents	Reference
	(A)	(B)	(C)	(D)	(E)
1	Medialis dorsalis	A	Principal: some from medioventral region (hypothalamus)	Frontal granular cortex.	2,4,16,19
2	Lateralis posterior	A	Principal: parietal cortex. Diffuse: sensorimotor, limbic, auditory, visual, frontal cortexes. From nuclei 5-9 in this table.	Parietal field.	2,4,10,13, 16,18, 19
3	Lateralis anterior	A	Principal: parietal cortex. Diffuse: sensorimotor, auditory, visual cortexes. From nuclei 5-9 in this table.		
4	Pulvinar	A	Principal: parietal association. Diffuse: frontal, sensorimotor, limbic, auditory, visual cortexes. Subcortical: ventral posterior nucleus of thalamus. From nuclei 5-9 in this table.	Posterior parietal and temporal cortex, superior parietal lobule, posterior Sylvian region, supramarginal gyrus, temporo-occipital region, cortical area 18, superior colliculus and pretectum, posterior parietal, temporal and occipital (parasensory) fields.	2,4,10,11, 13,16, 18-20
5	Centrum medianum	D	Subcortical: reticular formation; other intralaminar[1] thalamic nuclei	Subcortical: caudate nucleus, corpus striatum.	2,4,7,8, 12,16-18

/1/ Denotes nuclei not only adjacent to internal medullary lamina of thalamus but also others (such as midline nuclei, reticularis anterior and ventralis anterior) which, when stimulated, can evoke cortical and intrathalamic recruiting responses.

continued

37. BRAIN: MAN

Part III. NUCLEI OF METATHALAMUS AND DORSAL THALAMUS

	Nucleus	Function	Afferents	Efferents	Reference
	(A)	(B)	(C)	(D)	(E)
6	Centralis medialis	D	Reticular formation; intralaminar thalamic nuclei	Cortical associational areas: frontal, cingulate, orbital caudate nucleus.	2,4,7,8, 16-18
7	Centralis lateralis				
8	Ventralis anterior				
9	Reticularis anterior	D	Reticular formation; other intralaminar thalamic nuclei		
10	Anterodorsalis	I	Corresponding opposite nucleus	Retrosplenial region	2,4,16,19, 20
11	Anteromedialis	I	Mammillothalamic tract; limbic cortex. From nuclei 5-9 in this table.	Anterior gyrus cinguli	2,4,13,16, 18,20
12	Anteroventralis	I	Subcortical: from nuclei 5-9 in this table; mammillothalamic tract. Cortical: gyrus cinguli.	Posterior gyrus cinguli	2,4,13,16, 18,19
13	Ventral anterior	I	Principal: globus pallidus. Diffuse: orbital, parietal, frontal, sensorimotor, limbic cortexes. From nuclei 5-9 in this table.	Globus pallidus; prefrontal cortex	2,4,5,9, 13,16,18
14	Ventralis lateralis	I	Principal: superior cerebellar peduncle	Precentral motor cortex, areas 4 and 6. Brachium conjunctivum.	2,4,9,16, 19,20
15	Ventral medial	I		Globus pallidus; lateral frontal cortex	2,4,9,16
16	Medial geniculate body	E	Inferior colliculus and parabigeminal body; auditory cortex	Auditory cortex; parvicellular and magnocellular to temporal cortex in lower wall of Sylvian fissure	2,4,15,16
17	Lateral geniculate body	E	Ganglion cell layer of retina		2,4,16
18	Ventral posterolateral	E	Medial lemniscus; spinothalamic tract; sensorimotor cortex	Sensorimotor cortex	2-4,6,13, 14,16
19	Ventral posteromedial	E	Trigeminal lemniscus; trigeminal thalamic tract	Sensorimotor cortex	2,4,16
20	Reticularis lateralis (posterior)	U	Unclassified or doubtful	Cortex	1,2,4,16, 20
21	Midline[2]	D or U	Spinothalamic tract; medial lemniscus	Hypothalamus; basal ganglia; lateral thalamus nuclei	2,4,16-18,20

/2/ Midline nuclei: rhomboideus, reuniens, paracentralis, parafascicularis, paraventricularis (anterior and posterior), parataenialis.

Contributors: (a) Niemer, William T., (b) von Bonin, Gerhardt

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continued

37. BRAIN: MAN

Part IV. TRACTS

Abbreviations: C = cervical; S = sacral; T = thoracic.

	Tract	Origin	Termination	Pathway	Function
	(A)	(B)	(C)	(D)	(E)
1	Allen's fasciculus[1]	Solitary nucleus	Ventral column: C 3-T 6	Lateral funiculus along dorsolateral edge of ventral column	Associated with respiratory control
2	Arcuate fasciculus	Cerebral cortex of basal frontal lobes	Cortex of temporal, lower parietal, and occipital regions	Through base of angular gyrus into interior and middle frontal gyri; in parietal and frontal opercula over upper border of insula	Association bundle
3	Central acoustic	Contralateral and homolateral cochlear nucleus and olivary complex; nuclei of central acoustic tract	Medial geniculate body, inferior colliculus	With lateral lemniscus to ventrolateral surface of inferior colliculus; runs in brachium of inferior colliculus	Auditory
4	Corticospinal, lateral	Cerebral cortex	Contralateral anterior horn of spinal cord	Internal capsule; cerebral peduncle; decussation of pyramids, lateral corticospinal tract	Motor
5	Corticospinal, ventral	Cerebral cortex	Ipsilateral anterior horn of cord	Internal capsule; peduncle, ventral corticospinal tract about anterior median fissure of cord	Motor
6	Cuneate fasciculus	Dorsal root ganglia of C 1-T 6	Cuneate nucleus	Lateral portion of dorsal funiculus above T 6	Proprioception; discriminative touch (upper extremities)
7	Dorsolateral fasciculus (Lissauer)	Dorsal root fibers, fibers from substantia gelatinosa and dorsal horn of gray matter	Substantia gelatinosa (Rolando), nucleus proprius within 2-4 segments	Dorsolateral to substantia gelatinosa of dorsal horn of gray matter	Pain, temperature, and some tactile
8	Fastigiobulbar fasciculus	Fastigial nuclei	Reticular formation of medulla	Mingled with uncinate fasciculus of Russel in juxtarestiform body	Cerebellar inhibitory path from vermis bulbar reticular substance
9	Frontal fasciculus, superior (Burdach)	Basal frontal regions of cortex	Temporal, lower parietal, and occipital cortex	Dorsal to insula	Association fibers
10	Frontopontine fasciculus	Posterior part of superior and middle frontal gyri bordering on precentral gyrus	Pontine nuclei	Extreme medial and lateral portions of cerebral peduncle	Cortical relay fibers to middle lobe of cerebellum
11	Fasciculus gracilis (Goll)	Dorsal root ganglia of T 6-S 5	Nucleus gracilis	Medial portion of dorsal funiculus	Proprioception; discriminative touch (lower extremities)
12	Habenulopeduncular fasciculus[2]	Habenular nuclei	Interpeduncular nucleus	Runs ventrolaterally; arches beneath centrum medianum through medial border of red nucleus and along midventral line	
13	Habenulotegmental	Habenular nuclei	Dorsal tegmental nucleus		
14	Hypothalamic, descending[3]	Dorsomedial nuclei, posterior and lateral hypothalamic areas, perifornical areas	Autonomic cells in medulla oblongata and intermediolateral cell column of cord	Descends between mammillary body and red nucleus to ipsilateral reticular formation; dorsal to substantia nigra, then to region of vestibular fiber complex	
15	Interfascicular fasciculus (Schultze)	Descending fibers of posterior funiculus	Nucleus proprius of gray matter	Between, and mingled with, fasciculus gracilis and cuneatus	Reflex collaterals
16	Interstitiospinal (Cajal)	Mesencephalon, region of posterior commissure	Intermediolateral cell column of cord (C 8-T 1)	Descends along ventromedian sulcus of cervical cord	
17	Laterocerebellar	Lateral reticular nucleus of medulla	Cerebellum	Runs with external arcuate fibers	

/1/ Solitariospinal. /2/ Retroflex bundle of Meynert. /3/ Not yet demonstrated anatomically.

continued

37. BRAIN: MAN

Part IV. TRACTS

	Tract	Origin	Termination	Pathway	Function
	(A)	(B)	(C)	(D)	(E)
18	Longitudinal fasciculus, dorsal (Schütz)	Hypothalamus and dorsal tegmental nucleus	Somato-motor and autonomic motor nuclei of brain stem	Continue into ventral fasciculus propriua of cord	
19	Longitudinal fasciculus, inferior	Occipital cortex	Temporal cortex		Association fibers
20	Longitudinal fasciculus, medial	Mesencephalon, at level of posterior commissural nuclei	Through medulla, continued in cord as sulcomarginal fasciculus of Marie	Bilateral, about midventral line between central gray matter and tectospinal fasciculus (in medulla)	Contains vestibular reflex fibers, fibers from reticular nuclei, abducens nucleus
21	Mammillary fasciculus	Medial mammillary nuclei	Anterior thalamic nuclei and tegmentum	Runs dorsally from mammillary bodies, then bifurcates; one limb continues dorsally, the other caudally	
22	Mammillotegmental fasciculus	Medial and lateral mammillary nuclei	Tegmentum	Initially a component of the principal mammillary fasciculus which it leaves to run caudally	
23	Mammillothalamic fasciculus (Vicq d'Azyr)	Medial and lateral mammillary nuclei	Anterior nuclear mass of thalamus	Dorsorostrally through medial thalamic wall	
24	Olfactory	Olfactory bulb	In three striae: medial, intermediate, and lateral olfactory	Lies between gyrus rectus and medial orbital gyrus, covering olfactory sulcus	Olfaction
25	Olivocochlear bundle	Nuclei of olivary complex	Organ of Corti	Via auditory nerve	Inhibition of neural response from organ of Corti
26	Optic	Ganglion cells of retina	Lateral geniculate and/or superior colliculus	Tract encircles thalamus ventrally	Vision
27	Perpendicular fasciculus	Inferior parietal lobule	Fusiform gyrus	Obliquely dorsomedial and ventrolateral	Association
28	Probst's	Sensory cells associated with nucleus of cranial nerve V in area of cerebral aqueduct or lateral reticular nucleus of mesencephalon	Intercalated nucleus and dorsal vagal nucleus	Ventrolateral to solitary fasciculus, dorsomedial to nucleus of spinal tract of cranial nerve V	Appears to link various parts of trigeminal system; relating masticatory movements with salivation
29	Reticulospinal fasciculus, lateral, direct	Reticular substance	Gray matter of cord	Lies in region of overlap of lateral cortico- and rubro-spinal tracts	Extrapyramidal aspects of motor function
30	Reticulospinal fasciculus, ventral, crossed	Reticular substance	Gray matter of cord	Ventrolateral to ventral corticospinal fibers	Extrapyramidal aspects of motor function
31	Rubrospinal	Red nucleus	Gray matter of cord	Ventromedial to, and overlapping, lateral corticospinal tract	Extrapyramidal function
32	Septomarginal fasciculus	Collaterals of dorsal funiculus fibers (fasciculus cuneatus)	Gray matter of cord	Along posterior median sulcus in middle of posterior funiculus	Proprioceptive reflex connections
33	Solitary fasciculus	Fibers from cranial nerves VII, IX, and X	Solitary nucleus	Dorsomedial to spinal root of cranial nerve V; extends from level of medullary stria to caudal end of medulla	Visceral afferent; oral and concerned with taste
34	Spinal trigeminal	Cells of trigeminal nerve	Nucleus of spinal trigeminal tract	Ventromedial to restiform body; in position of Lissauer's zone	Pain, temperature, and some tactile from face

continued

37. BRAIN: MAN

Part IV. TRACTS

	Tract	Origin	Termination	Pathway	Function
	(A)	(B)	(C)	(D)	(E)
35	Spinocerebellar fasciculus, ventral	Border cells about medial border of centralateral ventral column, cells about dorsal nucleus of Clark	Vermis of anterior lobe of cerebellum	On periphery of cord ventral to dorsal spinocerebellar, and lateral to lateral spinothalamic tract	
36	Spinocerebellar fasciculus, dorsal (Flechsig)	Dorsal horn and dorsal nucleus of Clark	Cortex of anterior cerebellar lobe, uvula and pyramis of vermis	On periphery of lateral funiculus of cord	
37	Spinoolivary (Helweg)	Dorsal horn of spinal cord	Inferior olive	Ventral and superficial part of lateral funiculus between lateral and ventral spinothalamic tracts	
38	Spinothalamic, ventral[4]	Dorsal horn of gray matter (substantia gelatinosa)	Posterolateral ventral nucleus of thalamus	Lateral funiculus just medial to ventral spinocerebellar tract	Pain and temperature from extremities and trunk
39	Spinothalamic, ventral	Proper nucleus of contralateral dorsal horn	Posterolateral ventral nucleus of thalamus	Lateral portion of ventral funiculus	Light touch
40	Subcallosal fasciculus	Frontal cortex	Striate body	Dorsal to caudate nucleus below radiation of corpus callosum	
41	Tectospinal (Lowenthal)	Superior colliculus	Spinal gray matter	Ventromedial portion of ventral funiculus	Head and shoulder reflex movements to light and sound
42	Tegmental fasciculus, central	Variable composition		In reticular formation of medulla lateral to crossed vestibulospinal tract	
43	Tegmental fasciculus, central (part of)	Central gray matter of cerebral aqueduct	About sac of inferior olive	Flattened bundle running through tegmentum, oblique to horizontal plane, ventrolateral to medial longitudinal fasciculus	
44	Thalamic fasciculus	Fibers of brachium conjunctivum going to thalamus through tegmental field of Forel; fibers from globus pallidus	Thalamus; nucleus (ventralic anterior and ventralic lateralis)	Ventrally through Forel's field H_1, between mammillothalamic tract and lenticular fasciculus	
45	Vestibulofastigial	Vestibular nuclei and spinal nucleus of cranial nerve V	Fastigial nucleus and vermian cortex	Between restiform body and periventricular gray matter in juxtarestiform body	
46	Vestibuloflocculonodular	Cells of origin in vestibular ganglion (Scarpa)	Cortex of flocculus, nodulus of cerebellum		Vestibular
47	Vestibuloglobose	Vestibular nuclei and spinal nucleus of cranial nerve V	Globose nucleus and vermian cortex	Between restiform body and periventricular gray matter in juxtarestiform body	
48	Vestibulospinal, crossed, ventral	Medial, inferior, and spinal vestibular nuclei	Gray matter of cord	Medial portion of ventral funiculus in sulcomarginal fasciculus of Marie	Vestibular reflex
49	Vestibulospinal, direct, lateral	Lateral vestibular nucleus	Gray matter of cord	Ventrolateral part of ventral funiculus and ventromedial portion of lateral funiculus	Vestibular reflex

/4/ Lemniscae.

Contributors: (a) Sutin, Jerome, (b) Campbell, Berry

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38. AUTONOMIC NERVOUS SYSTEM: MAN

Both sympathetic and parasympathetic pathways contain afferent and efferent fibers, and the pathways are associated generally with the same viscera or vessels. Afferent sympathetic nerve cells are located in dorsal spinal nerve root ganglia. Their peripheral processes run in visceral and vascular nerves; their central processes enter the cord through dorsal nerve roots. Segmental numbers of nerve roots transmitting afferents from any viscus correspond usually to segments containing preganglionic neurones for that structure. Afferent parasympathetic nerve cells lie in root ganglia of cranial nerves V, VII, IX, and X, which are homologues of dorsal spinal root ganglia. Their peripheral processes run in the nerves indicated and carry impulses from glands and vessels; their central processes enter the brain stem. Afferent parasympathetic fibers from pelvic structures (cervix uteri, base of bladder, prostate, and rectum) are carried in the pelvic splanchnic nerves to the cord. Autonomic afferents participate in segmental reflex arcs. Relays also ascend in tracts in the anterolateral and posterior white columns of the cord to the brain stem and hypothalamus, where they may end or are further relayed to cortical levels, e.g., in the frontal lobes of the brain.

Contributor: Mitchell, G. A. G.

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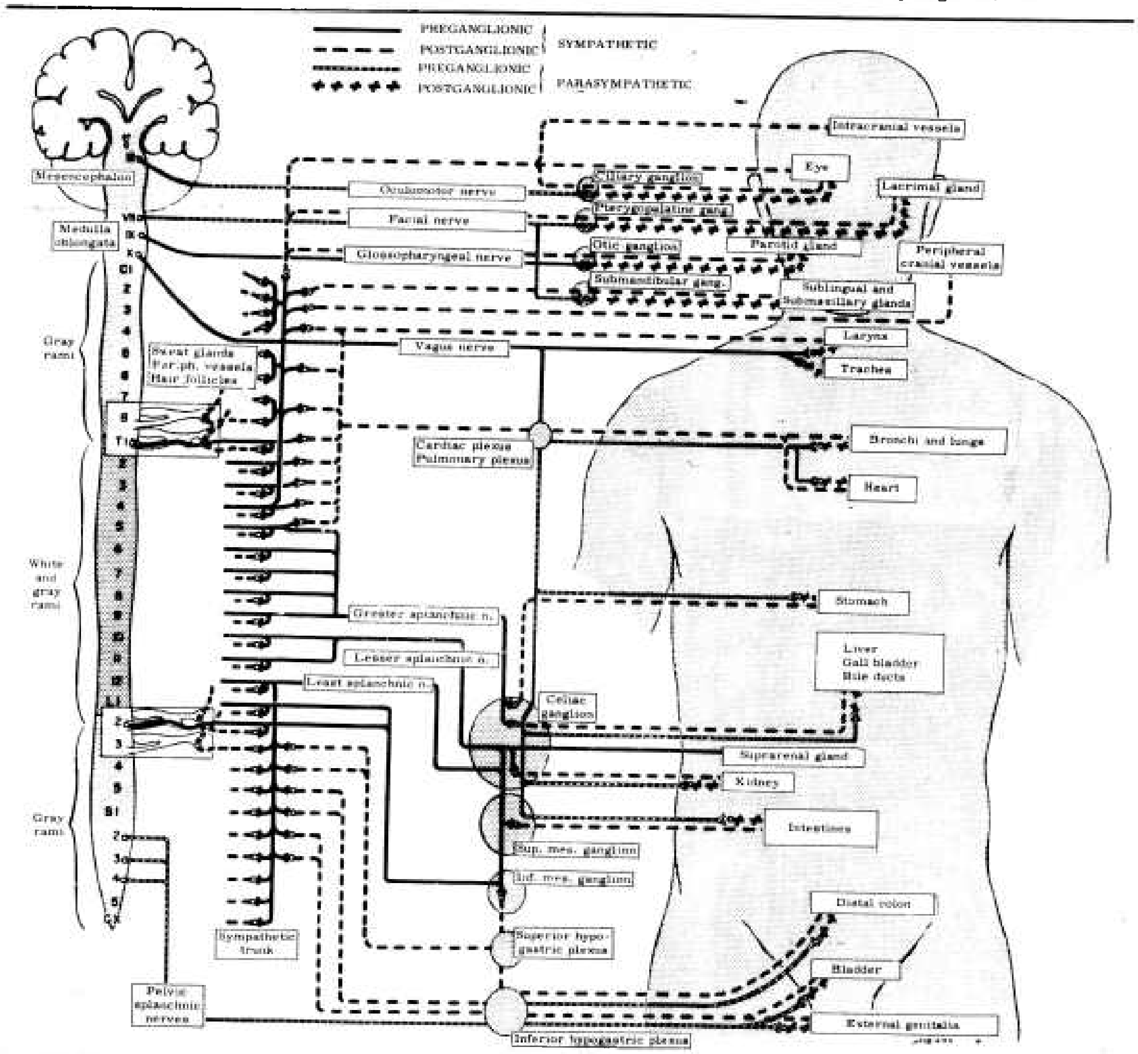

Contributors: Magoun, Horace, W., and Bridgman, Charles F.

continued

38. AUTONOMIC NERVOUS SYSTEM: MAN

Part I. SYMPATHETIC CONNECTIONS

Cell Body (column C): boldface type indicates cell bodies agreed upon by most investigators. **Pathway** (column D): WRC = white ramus communicans; ST = sympathetic trunk.

	Organ	Effector	Preganglionic Neurones		Postganglionic Neurones		Actions	Reference
			Cell Body	Pathway	Cell Body	Distribution		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
1	Eye	Dilator pupillae	T **1, 2**, 3[1]	WRC, ST	Superior cervical ganglion	Internal carotid plexus → short and long ciliary nerves	Dilation	12,13
2			C 8, **T 1, 2**	WRC, ST	Superior cervical ganglion	Internal carotid plexus → short and long ciliary nerves	Dilation	11
3		Muscle orbitalis	T **1, 2**, 3	WRC, ST	Superior cervical ganglion	Internal carotid plexus → ophthalmic nerve	?	12
4	Lacrimal gland	Blood vessels	T **1, 2**, 3	WRC, ST	Superior cervical ganglion	Internal carotid plexus and branches	Vasoconstriction	8,9
5	Heart	Mostly ventricular muscle, some atrial	T **1-5**	WRC, ST	Superior, middle, and inferior cervical ganglia; stellate and upper 4 or 5 thoracic ganglia	Superior, middle, and inferior cervical and thoracic cardiac nerves → cardiac plexus	Augmentation, acceleration	7,15
6	Coronary arteries	Smooth muscle	T **1-4** or **5**	WRC, ST	Superior, middle, and inferior cervical ganglia; stellate and upper 3 or 4 thoracic ganglia	Superior, middle, and inferior cervical and thoracic cardiac nerves → cardiac plexus → coronary plexuses	Vasodilation	5,14
7	Blood vessels	Meningeal arteries	T **1, 2**	WRC, ST	Superior cervical and internal carotid ganglia	External carotid and vertebral plexuses → meningeal arteries	Vasoconstriction	16
8		Cerebral arteries	T **1, 2**	WRC, ST	Superior cervical ganglion	Internal carotid plexus and branches	Vasoconstriction	
9		Vertebral system of brain	T **1, 2**	WRC, ST	Stellate ganglion	Vertebral plexus	Vasoconstriction	
10	Blood vessels, sweat glands, and piloerection muscles	Head, neck	T **1, 2**, 3[1]	WRC, ST	Superior cervical ganglion, internal carotid ganglia	Gray rami → cervical plexus, and certain cranial nerves and perivascular plexuses	Vasoconstriction	5,14
11		Upper limb	T 1, **2-9**, 10	WRC, ST	Superior, middle, and inferior cervical ganglia; stellate ganglion	Gray rami → brachial plexus and subclavian artery and branches	Sweating, piloerection, vasoconstriction	13
12		Thoracic and upper abdominal wall	T **2-10**	WRC, ST	Middle and inferior cervical, ganglia; stellate and upper thoracic ganglia	Gray rami → intercostal nerves	Sweating, piloerection, vasoconstriction	3
13		Lower limb and trunk	T **6-L 2**	WRC, ST	Lumbar 1-4; sacral 1-3	Gray rami → lumbar and sacral nerves	Sweating, piloerection, vasoconstriction	3
14	Suprarenal medulla	Cells of medulla	T 5-9, **10-L 1**, 2	WRC, ST (splanchnic)	Cells of suprarenal medulla	No postganglionic pathway	Secretion	5,14
15	Lung	Trachea and bronchi	T **2-4**	WRC, ST	Inferior cervical, stellate, and upper 4 thoracic ganglia	Tracheal and bronchial nerves	Tracheal and bronchial dilation	2,11
16		Blood vessels	T **2-4**	WRC, ST	Inferior cervical, stellate, and upper 4 thoracic ganglia	Pulmonary nerves and plexuses	Vasoconstriction	11

/1/ Occasionally C 8 and T 4.

continued

38. AUTONOMIC NERVOUS SYSTEM: MAN

Part I. SYMPATHETIC CONNECTIONS

	Organ	Effector	Preganglionic Neurones: Cell Body	Preganglionic Neurones: Pathway	Postganglionic Neurones: Cell Body	Postganglionic Neurones: Distribution	Actions	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
17	Submaxillary and sublingual glands	Gland and vessels	T 1, 2, 3	WRC, ST	Superior cervical ganglion	External carotid plexus and branches	Vasoconstriction, weak secretion	1,8
18	Parotid gland	Gland and vessels	T 1, 2, 3	WRC, ST	Superior cervical ganglion	External carotid plexus and branches	Vasoconstriction, weak secretion ?	1,8
19	Lower esophagus	Smooth muscle	T 1-3, 4-6	WRC, ST (greater splanchnic)	Stellate, upper thoracic, and celiac ganglia	Esophageal rami and plexus, left gastric and phrenic nerves	Inhibits peristalsis	6
20	Cardiac sphincter	Smooth muscle	T 1-3, 4-6	WRC, ST (greater splanchnic)	Stellate, upper thoracic, and celiac ganglia	Esophageal rami and plexus, left gastric and phrenic nerves	Contraction	6
21	Stomach	Smooth muscle and gland	T 5, 6-10, 11	WRC, ST (thoracic splanchnic)	Celiac ganglion	Accompanies gastric and gastroepiploic arteries	Inhibits peristalsis	5,14
22		Pyloric sphincter	T 5, 6-10, 11	WRC, ST (thoracic splanchnic)	Celiac ganglion	Accompanies right gastric artery	Contraction	
23		Blood vessels	T 5, 6-10, 11	WRC, ST (thoracic splanchnic)	Celiac ganglion	Accompanies gastric and gastroepiploic arteries	Vasoconstriction	
24	Pancreas	Gland	T 5, 6-10, 11	WRC, ST (thoracic splanchnic)	Celiac ganglion	Accompanies pancreatic arteries	Secretion ?	4
25		Blood vessels	T 5, 6-10, 11	WRC, ST (thoracic splanchnic)	Celiac ganglion	Accompanies pancreatic arteries	Vasoconstriction	5,14
26	Liver	Blood vessels	T 5, 6, 7-10	WRC, ST (splanchnic)	Celiac ganglion	Periarterial plexus of hypogastric artery	Vasoconstriction	5,14
27	Gallbladder	Smooth muscle	T 5, 6, 7-10	WRC, ST (splanchnic)	Celiac ganglion	Periarterial plexus of hepatic and cystic arteries	Relaxation	5,14
28		Sphincter of common bile duct	T 5, 6, 7-10	WRC, ST (thoracic splanchnic)	Celiac ganglion	Periarterial plexuses	Contraction	
29	Small intestine and proximal colon	Smooth muscle and glands	T 5, 6-10, 11	WRC, ST (thoracic splanchnic)	Celiac and superior mesenteric ganglia	Celiac and superior mesenteric rami	Secretion (?), inhibition	5,14
30	Ileocecal sphincter	Blood vessels and sphincter muscle	T 5, 6-10, 11	WRC, ST (thoracic splanchnic)	Celiac and superior mesenteric ganglia	Celiac and superior mesenteric rami	Vasoconstriction, contraction	5,14
31	Distal colon and rectum	Smooth muscle	T 12, L 1, 2, 3	WRC, ST (lumbar splanchnic)	Inferior mesenteric ganglion	Plexus of inferior mesenteric artery	Contraction, inhibition	5,14
32		Blood vessels	T 12, L 1, 2, 3	WRC, ST (lumbar splanchnic)	Inferior mesenteric ganglion	Plexus of inferior mesenteric artery	Vasoconstriction	
33	Internal sphincter ani	Blood vessels and sphincter muscle	L 1, 2, 3	WRC, ST (lumbar splanchnic)	Inferior mesenteric ganglion	Superior hypogastric plexus	Vasoconstriction, contraction	5,14
34	Kidney	Blood vessels and smooth muscle	T 5 - L 2	WRC, ST (thoracic splanchnic)	Aorticorenal or renal ganglion	Renal plexus	Vasomotor changes	5,14
35	Ureter	Blood vessels and smooth muscle	T 5 - L 2	WRC, ST (thoracic and lumbar splanchnic)	Aorticorenal or renal and inferior hypogastric ganglia	Renal plexus and hypogastric nerves	Rhythmic contraction	5,14
36	Bladder	Detrusor vesicae	L 1-3	WRC, ST (hypogastric nerves, inferior hypogastric plexus)	Vesical plexus, intramural ganglia	Intramural plexus	Relaxation	9

continued

38. AUTONOMIC NERVOUS SYSTEM: MAN

Part I. SYMPATHETIC CONNECTIONS

	Organ	Effector	Preganglionic Neurones		Postganglionic Neurones		Actions	Reference
			Cell Body	Pathway	Cell Body	Distribution		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
37	Bladder	Sphincter vesicae	L 1-3	WRC, ST (hypogastric nerves, inferior hypogastric plexus)	Vesical plexus	Intramural plexus	Constriction for ejaculation	10
38	Urethra	Compressor urethrae	L 1-3	WRC, ST (hypogastric nerves, inferior hypogastric plexus)	Vesical plexus, intramural ganglia	Prostatic plexus	Contraction	5,14
39	Prostate gland	Smooth muscle	T 12 - L 2	WRC, ST (hypogastric nerves, inferior hypogastric plexus)	Vesical and prostatic plexuses	Prostatic plexus	Contraction, ejaculation	5,14
40	Seminal vesicle and vas deferens	Smooth muscle	T 12 - L 2	WRC, ST (hypogastric nerves, inferior hypogastric plexus)	Vesical plexus	Plexuses of seminal vesicles and vasa deferentia	Contraction, ejaculation	5,14
41	Testis	Blood vessels	T 6-12	WRC, ST	Probably lower thoracic ganglia of sympathetic trunk	Thoracic splanchnic nerves → aortic and renal plexuses → spermatic plexus	Vasoconstriction	5,14
42	Corpora cavernosa	Blood vessels	T 12 - L 2	WRC, ST	Lumbar and sacral ganglia of sympathetic trunk	Inferior hypogastric plexus → prostatic plexus → cavernous plexus	Vasoconstriction	5,14
43	Clitoris, labia minora	Blood vessels	T 12 - L 2	WRC, ST	Lumbar and sacral ganglia of sympathetic trunk	Inferior hypogastric plexus → vaginal plexus → cavernous plexus	Vasoconstriction	5,14
44	Vagina	Smooth muscle	T 12 - L 2	WRC, ST (hypogastric nerves)	Inferior hypogastric and uter[illegible]-vaginal pl[illegible]	Vaginal plexus	Contraction	5,14
45	Ovary and uterine tube	Vascular bed and stroma	T 6-12	WRC, ST	Probably lo[illegible] thoracic gan[illegible] of sympathetic trunk	[illegible]ioracic splanchnic nerves → aortic and renal plexuses → ovarian plexus	Vasoconstriction, contraction	5,14

Contributors: (a) Rogers, William M., (b) Mitchell, G. A. G.

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continued

38. AUTONOMIC NERVOUS SYSTEM: MAN

Part II. PARASYMPATHETIC CONNECTIONS

Cell Body (column C): Boldface type indicates cell bodies agreed upon by most investigators.

	Organ	Effector	Preganglionic Neurones		Distribution of Postganglionic Neurones	Actions	Reference
			Cell Body	Pathway			
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
1	Eye	Sphincter pupillae	Accessory (autonomic) oculomotor nucleus	Oculomotor nerve → motor root → ciliary ganglion	Ciliary ganglion → short ciliary nerves	Constriction of pupil	3,7
2		Ciliary muscle	Accessory (autonomic) oculomotor nucleus	Oculomotor nerve → motor root → ciliary ganglion	Ciliary ganglion → short ciliary nerves	Accommodation	12
3	Lacrimal gland	Gland cells	Nucleus salivatorius superior	Nervus intermedius → greater petrosal nerve → nerve of pterygoid canal	Pterygopalatine ganglion → zygomatic nerve → lacrimal nerve	Secretion	12
4	Heart	Sinoatrial node; atrioventricular node, conduction system; cardiac muscle	Dorsal motor nucleus of vagus	Superior, inferior, and thoracic cardiac rami of vagus	Intrinsic cardiac ganglia	Inhibitory; decreases heart rate	5
5	Coronary arteries	Smooth muscle	Dorsal motor nucleus of vagus	Superior, inferior, and thoracic cardiac rami of vagus	Intrinsic cardiac ganglia, adventitia and branches of coronary artery	Constriction	13
6	Blood vessels	Smooth muscle	Demonstrated only for brain, meninges, face, most glands, and pelvic and genital organs			Vasoconstriction	12
7	Suprarenal medulla	None demonstrated					12
8	Spleen	None demonstrated					12
9	Lung and trachea	Smooth muscle of trachea, bronchial tree	Dorsal motor nucleus of vagus	Vagal branches → anterior and posterior pulmonary, and cardiac plexuses	Intramural tracheal and bronchial ganglia	Tracheal and bronchial constriction	12
10		Tracheal and bronchial glands	Dorsal motor nucleus of vagus	Vagal branches → anterior and posterior pulmonary, and cardiac plexuses	Intramural tracheal and bronchial ganglia	Secretion	
11	Submaxillary and sublingual glands	Gland cells and blood vessels	Nucleus salivatorius superior	Nervus intermedius → 7th nerve → chorda tympani → lingual nerve	Submaxillary ganglion → submaxillary and sublingual branches	Secretion, vasodilation	6
12	Parotid gland	Gland cells and blood vessels	Nucleus salivatorius inferior	9th nerve → tympanic nerve → lesser petrosal nerve	Otic ganglion → auriculotemporal nerve	Secretion, vasodilation	12
13	Lower esophagus	Smooth muscle	Dorsal motor nucleus of vagus	Vagus nerve → esophageal plexus	Myenteric ganglionated plexus	Increases tonus; peristalsis	12
14		Cardiac sphincter	Dorsal motor nucleus of vagus	Vagus nerve → esophageal plexus	Myenteric ganglionated plexus	Relaxation	
15	Stomach	Smooth muscle	Dorsal motor nucleus of vagus	Vagus nerve → gastric branches	Myenteric plexus	Contraction; increases tonus; peristalsis	2
16		Gastric glands	Dorsal motor nucleus of vagus	Vagus nerve → gastric branches	Submucosal plexus	Secretion	11
17	Pyloric sphincter	Smooth muscle	Dorsal motor nucleus of vagus	Vagus nerve → pyloric branches	Myenteric plexus	Inhibitory; diminishes tonus	12
18	Pancreas	Gland cells and blood vessels	Dorsal motor nucleus of vagus	Vagus nerve → pancreatic branches	Pancreatic ganglia	Secretion, vasodilation	12

continued

38. AUTONOMIC NERVOUS SYSTEM: MAN

Part II. PARASYMPATHETIC CONNECTIONS

	Organ	Effector	Preganglionic Neurones		Distribution of Postganglionic Neurones	Actions	Reference
			Cell Body	Pathway			
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
19	Liver	Hepatic cells, blood vessels, ducts	Dorsal motor nucleus of vagus	Vagus nerve → hepatic branches	Intramural ganglia	Secretion?	12
20	Gallbladder	Smooth muscle	Dorsal motor nucleus of vagus	Vagus nerve → hepatic and cystic plexuses	Intramural ganglia	Emptying of gallbladder	5
21	Biliary tree	Smooth muscle	Dorsal motor nucleus of vagus	Vagus nerve → hepatic and gastroduodenal plexuses	Intramural ganglia	Elevates pressure of bile ducts	5
22	Sphincter of common bile ducts	Smooth muscle	Dorsal motor nucleus of vagus	Vagus nerve → hepatic and gastroduodenal plexuses	Intramural ganglia	Relaxation	5
23	Small intestine	Smooth muscle	Dorsal motor nucleus of vagus	Vagus nerve → celiac and superior mesenteric branches	Myenteric plexus	Contraction, peristalsis	12
24		Gland	Dorsal motor nucleus of vagus	Vagus nerve → celiac and superior mesenteric branches	Submucosal plexus	Secretion	
25	Ileocecal sphincter	Smooth muscle	Dorsal motor nucleus of vagus	Vagus nerve → celiac and superior mesenteric branches	Myenteric plexus	Inhibitory; diminishes tonus	12
26	Proximal colon	Smooth muscle	Dorsal motor nucleus of vagus	Vagus nerve → celiac and superior mesenteric branches	Myenteric gangliionated plexus	Contraction, peristalsis	12
27		Glands	Dorsal motor nucleus of vagus	Vagus nerve → celiac and superior mesenteric branches	Submucosal ganglionated plexus	Secretion	
28	Distal colon	Smooth muscle	S 2-4	Pelvic splanchnic nerves → hypogastric nerves → inferior mesenteric plexus	Myenteric plexus	Contraction, vasodilation; peristalsis	1
29		Glands	S 2-4	Pelvic splanchnic nerves → hypogastric nerves → inferior mesenteric plexus	Submucosal plexus	Secretion	
30		Internal sphincter ani	S 2-4	Pelvic splanchnic nerves → inferior hypogastric plexus	Myenteric plexus	Inhibition, vasodilation	
31	Kidney	None demonstrated					12
32	Ureter	Smooth muscle	S 2-4	Pelvic splanchnic nerves → hypogastric nerves	Intramural ganglia	Contraction	9
33	Bladder	Detrusor vesicae	S 2, 3, 4	Pelvic splanchnic nerves (nervi erigentes)	Inferior hypogastric plexus → vesical and intramural ganglia	Contraction	8,10
34		Sphincter vesicae	S 2, 3, 4	Pelvic splanchnic nerves (nervi erigentes)	Inferior hypogastric plexus → vesical and intramural ganglia	Relaxation	8
35	Urethra	Smooth muscle	S 2, 3, 4	Pelvic splanchnic nerves	Inferior hypogastric plexus → vesical plexus → prostatic plexus	Control of sphincter	8
36	Prostate gland	Smooth muscle	S 2, 3, 4	Pelvic splanchnic nerves	Inferior hypogastric plexus → vesical plexus → prostatic plexus	?	12
37	Seminal vesicle and vas deferens	Smooth muscle	S 2, 3, 4	Pelvic splanchnic nerves	Inferior hypogastric and vesical plexuses	?	12
38	Testis	None demonstrated					12

continued

38. AUTONOMIC NERVOUS SYSTEM: MAN

Part II. PARASYMPATHETIC CONNECTIONS

	Organ	Effector	Preganglionic Neurones		Distribution of Postganglionic Neurones	Actions	Reference
			Cell Body	Pathway			
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
39	Corpora cavernosa	Erectile tissue	S 2, 3, 4	Pelvic splanchnic nerves	Inferior hypogastric plexus → cavernous plexus	Vasodilation, erection	10
40	Clitoris and labia minora	Erectile tissue	S 2, 3, 4	Pelvic splanchnic nerves	Inferior hypogastric plexus → uterovaginal plexus	Vasodilation, erection	10
41	Vagina	None demonstrated					4
42	Cervix of uterus	Smooth muscle	S 2-4	Pelvic splanchnic nerves	Inferior hypogastric plexus	?	12
43	Uterine tube	None demonstrated					12
44	Ovary	None demonstrated					12
45	Thyroid gland	No true secretory fibers present					12
46	Face	Blood vessels	Nucleus salivatorius superior ?	Nervus intermedius → 7th nerve	Vascular rami from 7th nerve to external carotid artery and its branches	Vasodilation, blushing	12
47	Mucosal glands of palate	Gland cells	Nucleus salivatorius superior	Nervus intermedius → great superficial petrosal nerve → vidian nerve	Pterygopalatine ganglion and palatine nerves	Secretion	12

Contributors: (a) Rogers, William M., (b) Mitchell, G. A. G.

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Part III. GANGLIA

Division (column B): S = sympathetic; P = parasympathetic.

	Ganglion	Division	Location	Preganglionic Connections	Postganglionic Distribution
	(A)	(B)	(C)	(D)	(E)
1	Aorticorenal	S	Root of renal artery	Thoracic splanchnic nerves	Renal and aortic plexuses
2	Bronchial	P	Bronchial plexuses	Vagus nerves	Bronchial musculature and glands
3	Cardiac	P	Cardiac plexus	Vagus nerves	Heart, coronary vessels, pulmonary plexuses
4	Celiac	S	Celiac plexus	Thoracic splanchnic nerves	Abdominal viscera and blood vessels
	Cervical sympathetic				
5	Inferior	S	Sympathetic trunk, level of vertebra T 1	Upper thoracic nerves	Brachial plexus, inferior cervical cardiac nerve, common carotid plexus, vertebral nerves

continued

38. AUTONOMIC NERVOUS SYSTEM: MAN

Part III. GANGLIA

	Ganglion	Division	Location	Preganglionic Connections	Postganglionic Distribution
	(A)	(B)	(C)	(D)	(E)
	Cervical sympathetic				
6	Middle	S	Sympathetic trunk, level of vertebra C 6	Upper thoracic nerves	Middle cervical cardiac nerve, sympathetic roots of nerves C 5, 6
7	Superior	S	Sympathetic trunk opposite 2nd, 3rd, 4th cervical vertebrae	Upper thoracic nerves	Internal, external carotid nerves, sympathetic roots of nerves C 1-3, superior cervical cardiac nerves
8	Cervical of uterus	P,S	Inferior hypogastric plexus adjacent to cervix of uterus	Pelvic splanchnic nerves, inferior hypogastric plexus	Uterus and vagina
9	Ciliary	P	Orbit, between optic nerve and lateral rectus muscle	Oculomotor	Short ciliary nerves
10	Enteric	P	Wall of enteric canal	Vagus and pelvic splanchnic nerves	Enteric muscles and glands
11	Impar (coccygeal)	S	Ventral surface of coccyx	Lumbar spinal nerves	Caudal spinal nerves
12	Intermediate	S	In relation to ventral nerve roots and communicating rami	Ventral nerve roots	Primary ventral rami of spinal nerves, visceral nerves
13	Lingual	P	Tongue	Facial and chorda tympani	Lingual glands
	Mesenteric				
14	Inferior	S	Adjacent to inferior mesenteric artery	Lumbar splanchnic nerves	Inferior mesenteric and superior hypogastric plexuses
15	Superior	S	Adjacent to root of superior mesenteric artery	Thoracic splanchnic nerves	Superior mesenteric, aortic, and renal plexuses
16	Myenteric	P	Between longitudinal and circular enteric muscle layers	Vagus and pelvic splanchnic nerves	Enteric muscles
17	Otic	P	Medial to mandibular nerve, just below foramen ovale	Glossopharyngeal nerve	Supplies auriculotemporal nerve with fibers to parotid gland
18	Pelvic	P,S	Adjacent to pelvic viscera	Pelvic splanchnic nerves, inferior hypogastric plexus	Pelvic viscera and blood vessels, and vessels in external genitalia
19	Pterygopalatine[1]	P	Pterygopalatine fossa	Facial nerve	Pharyngeal, palatine, nasal, and orbital nerves
20	Pulmonary	P	Pulmonary plexuses	Vagus nerves	Bronchial plexuses
21	Splanchnic	S	Posterior mediastinum in relation to thoracic splanchnic nerves	Thoracic splanchnic nerves	Celiac plexus
22	Submandibular	P	Between lingual nerve and duct of submandibular gland	Chorda tympani (through facial)	Submandibular, sublingual, and lingual glands
23	Submucous	P	Submucosa of enteric canal	Vagus and pelvic splanchnic nerves	Enteric muscles and glands
24	Sympathetic trunk	S	Ventrolateral to vertebral column	Spinal nerves T 1 - L 2	Sympathetic roots of spinal nerves, cephalic sympathetic, cardiac and splanchnic nerves
25	Terminale	P	Adjacent to olfactory tract	Nervus terminalis	Anterior cerebral artery, vomeronasal organ, nasal mucosa
26	Tracheal	P	Tracheal wall	Vagus nerves	Tracheal and bronchial plexuses
27	Vertebral	S	Sympathetic trunk, level of vertebra C 8	Upper thoracic nerves	Ansa subclavia, inferior cervical cardiac nerve, vertebral nerves, sympathetic roots of nerves C 6, 7, 8

/1/ Supplied by greater petrosal through facial nerve.

Contributors: (a) Kuntz, Albert, (b) Mitchell, G. A. G.

Reference: Kuntz, A. 1953. The autonomic nervous system. Ed. 4. Lea and Febiger, Philadelphia.

continued

38. AUTONOMIC NERVOUS SYSTEM: MAN

Part IV. PLEXUSES

Division (column B): S = sympathetic; P = parasympathetic.

	Plexus	Division	Origin	Distribution
	(A)	(B)	(C)	(D)
1	Aortic	S	Sympathetic trunks	Aorta and proximal portions of its branches
	Cardiac			
2	Superficial	P,S	Cervical and thoracic sympathetic cardiac nerves, branches of vagus nerves	Heart, coronary vessels, anterior pulmonary plexuses
3	Deep	P,S	Right superior, middle and inferior cervical and thoracic sympathetic cardiac nerves; all cardiac branches of right vagus, left middle and inferior cervical and thoracic cardiac nerves, superior cervical and cardiac branches of left vagus	Heart, coronary vessels, anterior pulmonary plexuses
	Carotid			
4	Common	S	Sympathetic trunk	Common carotid artery
5	External	S	Superior cervical ganglion, common and external carotid plexuses	External carotid artery and its branches
6	Internal	S	Superior cervical ganglion, common and internal carotid plexuses	Internal carotid artery and its branches, caroticotympanic and deep petrosal nerves, cavernous plexus
7	Cavernous	S	Internal carotid plexus	Cavernous sinus, oculomotor, trochlear and ophthalmic nerves, ciliary ganglion, hypophysis cerebri
8	Celiac	S	Intrinsic ganglia, splanchnic nerves	Celiac artery and its branches
9	Colic	S	Inferior mesenteric plexus	Colon and rectum
10	Duodenal	S	Gastroduodenal, superior mesenteric, and pancreatic plexuses	Duodenum and pancreas
11	Enteric	P	Vagus, pelvic splanchnic nerves, intrinsic ganglia; esophageal, celiac, mesenteric, and pelvic plexuses	Enteric canal
12	External carotid	S	External carotid plexus	External carotid artery, submandibular and otic ganglia
13	Hepatic	P,S	Vagus nerves and celiac plexus	Biliary system, hepatic blood vessels
14	Hypogastric	S	Celiac, aortic, inferior mesenteric plexuses	Inferior hypogastric plexus
15	Spermatic	S	Aortic and renal plexuses	Spermatic artery, spermatic cord, testis
	Mesenteric			
16	Inferior	S	Celiac plexus, lumbar splanchnic nerves	Inferior mesenteric artery and its branches
17	Superior	S	Celiac plexus	Superior mesenteric artery and its branches
18	Meningeal, middle	S	External carotid plexus	Middle meningeal artery
19	Ovarian	S	Aortic and renal plexuses	Ovarian artery, ovary
20	Pancreatic	P,S	Vagus nerves, intrinsic ganglia, sympathetic trunks	Pancreas, pancreatic ducts and vessels
21	Pelvic	P,S	Inferior hypogastric plexus, pelvic splanchnic nerves, intrinsic ganglia	Pelvic viscera and blood vessels, and vessels of erectile tissue
22	Pulmonary	P,S	Vagus nerves, intrinsic ganglia, sympathetic trunks	Bronchial plexuses, pulmonary vessels
23	Phrenic	S	Celiac plexus, lesser and least splanchnic nerves	Renal blood vessels; supplies suprarenal gland, diaphragm, esophagus, inferior vena cava
24	Prostatic	P,S	Inferior hypogastric plexus	Prostate gland
25	Renal	S	Celiac plexus, thoracic splanchnic nerves	Renal blood vessels
26	Sigmoid	S	Inferior mesenteric plexus	Sigmoid colon
27	Splenic	S	Celiac plexus	Spleen, pancreas, stomach
28	Suprarenal	S	Celiac plexus	Suprarenal artery and gland
29	Tympanic	P,S	Internal carotid nerve, ramus from geniculate ganglion	Tympanum, mastoid cells, auditory tube
30	Uterine	P,S	Inferior hypogastric plexus	Uterus
31	Vaginal	P,S	Inferior hypogastric plexus	Vagina
32	Vesical	P,S	Inferior hypogastric plexus	Urinary bladder

Contributors: (a) Kuntz, Albert, (b) Mitchell, G. A. G.

Reference: Kuntz, A. 1953. The autonomic nervous system. Ed. 4. Lea and Febiger, Philadelphia.

39. DIGESTIVE ENZYMES: VERTEBRATES

Tissue or Secretion (column D): T = tissue; S = secretion. *Symbols* (columns E-S): + = present; - = absent; ± = doubtful. For information on monkey, consult references 3, 17, 28; for mouse, references 18, 13.

	Species	Common Name	Organ	Tissue or Secretion	Enzyme: Amylase (Diastase)	Carbonic Anhydrase	Elastase	Enterokinase	Erepsin, Peptidase	Invertase (Saccharase)	Lipase, Esterases	Maltase	Pepsin	Phosphatase	Ribonuclease	Rennin (Chymosin)	Trypsin, Other Non-acid Proteases	Urease	β-D-Galactosidase	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)	(P)	(Q)	(R)	(S)	(T)
1	*Homo sapiens*	Man	Salivary gland	T							+									5
2				S	+				+		+			+						17
3			Esophagus	T							+									5
4			Stomach	T							+		+	+				+		K,5;M,N,17;R,10
5				S							+		+			-[1]				K,24;M,17;P,11
6			Pancreas	T					+		+									24
7				S	+				+		+	+					+			E,L,Q,4;I,K,24
8			Small intestine	T	+				+					+						E,17;I,24;N,23,26
9				S	±			+	+	+	±									E,24;H-K,31
10			Cecum & colon	T										+						26
11	*Bos taurus*	Cattle (cow)	Salivary gland	T							+			+					+	8
12				S	+						+									E,8;K,17
13			Esophagus	T									-							24
14			Stomach	T	+						+					+[2]		+		E,R,26;K,17;P,5
15				S									+			±[2]				M,4;P,17
16			Pancreas	T	+						+				+		+			E,24;K,17;O,Q,5
17				S	+												+			24
18			Small intestine	T									-	+						M,24;N,15
19				S				+												17
20	*Capra hircus*	Goat	Salivary gland	S	-															24
21			Stomach	T														-		26
22				S												+[2]				26
23			Small intestine	S	±			+	-	±	±						-			E,I-K,Q,31;H,17
24	*Ovis aries*	Sheep	Salivary gland	T							+			+					+	8
25				S	-						+									17
26			Esophagus	T									-							24
27			Stomach	T							+		+			+[2]		+		K,17;M,R,26;P,5
28			Pancreas	T	+						+				+		+			E,K,17;O,2;Q,26
29				S	+												+			E,17;Q,26
30			Small intestine	S				+												17
31			Cecum & colon	T							-									24
32	*Sus scrofa*	Swine	Salivary gland	T							+			+					+	8
33				S	+															17
34			Esophagus	T									-							24
35			Stomach	T					+		±		+					+		I,M,17;K,13;R,10
36				S	-								+			+[2]				E,M,12;P,17
37			Pancreas	T	+		+		+		+			+	+		+			E,I,K,Q,17;G,20; K,14;N,18;O,25
38				S	+		+										+			E,Q,24;G,20
39			Small intestine	T				+	-		+		±	+						H,25;I,31;K,17; M,24;N,26
40				S	+			+		±	±						-			E,J,K,Q,31;H,17
41	*Equus caballus*	Horse	Salivary gland	S	±						+									E,24;K,26
42			Stomach	T							+									17

/1/ In adult. /2/ Only in young.

continued

	Species	Common Name	Organ	Tissue or Secretion	Enzyme															Reference
					Amylase (Diastase)	Carbonic Anhydrase	Elastase	Enterokinase	Erepsin, Peptidase	Invertase (Saccharase)	Lipase, Esterases	Maltase	Pepsin	Phosphatase	Ribonuclease	Rennin (Chymosin)	Trypsin, Other Non-acid Proteases	Urease	β-D-Galactosidase	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)	(P)	(Q)	(R)	(S)	(T)
43	*Equus caballus*	Horse	Small intestine	T									-							24
44				S[3]	+			+		+	-	+					+			E, J-L,Q,1;H,17
45			Cecum & colon	T	+															29
46	*Felis catus*	Cat	Salivary gland	T										+						26
47				S	-															17
48			Stomach	T		+					+			+				+		F,4;K,17;N,26;R,10
49				S									+							4
50			Pancreas	T		+			+			+		±						F,L,4;I,17;N,26
51				S	+						+									4
52			Small intestine	T		+		+	±					+			+			F,4;H,I,Q,17;N,23,26
53				S	+			+	±	±	-						-			E,I,J,Q,31;H,17;K,26
54			Cecum & colon	T							+			+						K,22;N,26
55			Colon	S							-									22
56	*Canis familiaris*	Dog	Salivary gland	T		+					+			+					+	F,6;K,N,S,8
57				S	+						+									E,8;K,17
58			Esophagus	T									-							24
59			Stomach	T		+					+							+		F,4;K,24;R,10
60				S	±						+		+			±[2]				E,K,24;M,P,3
61			Pancreas	T	+		+		+		+				+		+			E,I,K,Q,4;G,7;O,25
62				S	+				+		+	+					+			4
63			Small intestine	T				+	+		+			+						H,4;I,K,24;N,26
64				S	+			+	+	±	±						±			E,J,K,Q,31;H,I,4
65			Cecum & colon	S	±			-	±		+									E,K,24;H,I,19
66	*Cavia porcellus*	Guinea pig	Salivary gland	S	+															17
67			Stomach	T		+					+									F,18;K,17
68			Pancreas	T		+	+		+											F,18;G,9;I,17
69				S							+									24
70			Small intestine	T					+					+						I,17;N,23
71	*Rattus* spp.	Rat	Salivary gland	T							+			+					+	8
72				S	+															27
73			Stomach	T	+	+					+		+					+		E,21;F,4;K,17;M,26;R,10
74				S									+							16
75			Pancreas	T	+	+	+				+						+			E,F,K,Q,4;G,9
76				S	+															4
77			Small intestine	T	+	+		+	+			+		+						E,I,L,30;F,4;H,N,23,26
78			Colon	T	+															21
79	*Oryctolagus cuniculus*	Rabbit	Salivary gland	T							+			+					+	8
80				S	+															8
81			Stomach	T		+					+		+	+				+		F,4;K,17;M,24;N,26;R,10
82				S							+									24
83			Pancreas	T		+			+											F,4;I,17
84				S	+						+						+			4

/2/ Only in young. /3/ Lactase also present [1].

continued

	Species	Common Name	Organ	Tissue or Secretion	Enzyme: Amylase (Diastase)	Carbonic Anhydrase	Elastase	Enterokinase	Erepsin, Peptidase	Invertase (Saccharase)	Lipase, Esterases	Maltase	Pepsin	Phosphatase	Ribonuclease	Rennin (Chymosin)	Trypsin, Other Non-acid Proteases	Urease	β-D-Galactosidase	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)	(P)	(Q)	(R)	(S)	(T)
85	*Oryctolagus cuniculus*	Rabbit	Small intestine	T		+			+				-	+						F,4;I,M,24;N,26
86				S	+			+	-		±						-			E,I,K,Q,31;H,17
87			Cecum & colon	T									+							26
88	*Gallus domesticus*	Chicken	Salivary gland	S	+															17
89			Stomach	T							+		+							K,17;M,5
90			Pancreas	T	+															17
91			Small intestine	T	+									+						E,17;N,23
92	*Rana* spp.	Frog	Salivary gland	S	+															17
93			Esophagus	T									+							24
94			Stomach	T									+					+		M,17;R,10
95				S									+							17
96			Pancreas	T					+			+					+			I,17;L,Q,26
97			Small intestine	T					+			-								I,17;L,26

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Part I.

For a comprehensive review of the

	Component	Mammalia: *Homo sapiens*	Mammalia: *Bos taurus*	Mammalia: *Canis familiaris*	Aves
	(A)	(B)	(C)	(D)	(E)
1	Sinus venosus	Sinus venosus completely incorporated into right atrium[3]. Sinoatrial node same as in *Bos* and *Canis*.	Incorporated into right atrium. Sinoatrial node, or "pacemaker," is specialized tissue in atrial region (was part of sinus in embryo).		Largely included in right atrium.
2	Sinoatrial junction	Vestige of embryonic sinoatrial junction found in adult right atrium.	Right valve of embryonic sinus becomes valve of inferior vena cava and of coronary sinus.		Embryonic right sinal valve becomes valve of inferior vena cava.
3	Atrium	Complete interatrial septum except for small remnant of foramen ovale. Sinoatrial and atrioventricular nodes connected by typical cardiac fibers of right atrium.	Complete interatrial septum. Histological characteristics of sinoatrial and atrioventricular nodal fibers unusually clear.	Complete interatrial septum. Sinoatrial node near opening of superior vena cava, atrioventricular node near opening of coronary sinus.	Complete interatrial septum. Extensive distribution of specialized conduction fibers.
4	Atrioventricular junction	Atrioventricular ring of dense connective tissue. Right atrioventricular valve is tricuspid, left valve is bicuspid. Atrioventricular bundle of His present from atrioventricular node to ventricles. In the adult, usually no muscular atrioventricular connections other than the bundle of His [9].	Connective tissue of atrioventricular ring (annulus fibrosus) contains bone. Atrioventricular bundle is usually distinct. Right atrioventricular valve usually tricuspid, left valve usually bicuspid.	Atrioventricular valves the same as in *Bos*. Ring of connective tissue separates atrial and ventricular muscle, except for atrioventricular bundle of His.	Atrial and ventricular muscles separated by ring of connective tissue, except for atrioventricular bundles. Right atrioventricular valve is large and muscular, left valve is bicuspid.
5	Ventricle	Complete interventricular septum, membranous in uppermost reaches.	Complete septum. Histological characteristics of Purkinje (conduction) fibers distinct.	Complete ventricular septum.	Complete ventricular septum.
6	Conus arteriosus	Proximal portion incorporated in right ventricle, distal incorporated in left aortic and pulmonary trunks.			Proximal portion incorporated in right ventricle, distal incorporated in right aortic and pulmonary trunks.
7	Truncus arteriosus[5]	Divided into aortic and pulmonary trunks. Semilunar valves at embryonic juncture of conus and truncus.			

/1/ Data for Crocodylia from White [13]. /2/ Data from Favaro [3]. /3/ Some authorities are of the opinion that a are present in the turtle and in lower forms is supported by Robb [12], while the view that a specialized conduction expanded portion of the ventral aorta lying within the pericardial cavity; also known as the bulbus arteriosus, or

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subject, consult references 4, 8, 10.

Reptilia[1]	Amphibia	Pisces and Chondrichthyes	Agnatha[a]	
(F)	(G)	(H)	(I)	
Partly incorporated into right atrium, and is distinct only internally. Chelonia: Origin of beat is dependent on intrinsic ganglia [6].	Salientia: Separate chamber and relatively smaller than in Caudata. Caudata: Thin-walled, triangular-shaped chamber, shifted toward right side.	Smooth, thin-walled chamber into which systemic veins open. Cardiac muscle has high intrinsic contraction rate and acts as the "pacemaker" (although contraction is myogenic in origin, rate of beat is under nervous control, being depressed by vagal stimulation and accelerated by sympathetic stimulation).	Thin-walled, elongated sac or tube into which systemic veins open.	1
Approximately the same as in Pisces.		Sinoatrial opening guarded by pair of valves. Cardiac muscle continuous from sinus to atrium.	Sinoatrial opening guarded by pair of valves.	2
Same as in Salientia, but interatrial septum contributes to valves dividing atrioventricular opening in two.	Salientia: Complete interatrial septum. Caudata: Incomplete septum partially dividing chamber bilaterally, with sinus venosus opening into right atrium and single pulmonary vein into left atrium.	Thin, reticulate-walled chamber; no division into right and left sides, no pulmonary veins. Dipnoi: Partial septation. Pulmonary vein enters to left and sinus venosus to right of septum.	Single muscular sac. Atrium lateral to ventricle.	3
Crocodylia: Atrioventricular ring contains cartilage extending into base of right atrioventricular valve and similar valve of right aortic arch. Chelonia: Continuity of muscle, as in teleosts. Presence of "Purkinje-like" fibers controversial.[4]	Continuity of atrial and ventricular muscles, as in Pisces. Salientia: Four valve cusps. Caudata: Atrioventricular valve of two or four muscular thickenings.	Atrioventricular valve composed of two cusps. Cardiac muscle of atrium continuous with that of ventricle around entire circumference of atrioventricular junction. Dipnoi: Fibrocartilaginous plug regulates blood flow.	Atrioventricular channel connects both vesicles. Two valves present.	4
Serpentes, Sauria, Chelonia: Ventricle partially divided by incomplete septum. Crocodylia: Complete ventricular septum containing cartilage.	No ventricular septum.	Thick-walled chamber; network of muscular trabeculae; no division into right and left sides. Dipnoi: Septum present.	Thick-walled muscular sac with smooth internal surface.	5
Conus incorporated in ventricle and in arterial trunks.	Semilunar valves; also a "spiral valve" coursing lengthwise.	Semilunar valves present. Pisces: Small. Dipnoi: Divided into dorsal and ventral channels. Chondrichthyes: Relatively large.	Absent, unless two valves may be regarded as remnants.	6
Crocodylia: Right and left systemics connected by foramen of Panizza. Chelonia: Divided into right and left systemic and pulmonary trunks.	Salientia: Divided both internally and externally into right and left channels. Caudata: Divided internally into right and left channels.	Pisces: Enlarged in species having reduced conus in shape of bulbus arteriosus. Dipnoi: Divided into three paired channels.	Part bordering on ventricle enlarged to form bulbus arteriosus.	7

small part of the sinus venosus is also incorporated in the left atrium [5]. /4/ The view that "Purkinje-like" fibers system of Purkinje fibers is neomorphic for birds and mammals is supported by Davies and Francis [2]. /5/ An aortic sac [1, 7, 11].

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Part II. BLOOD

	Vessel (A)	Mammalia (B)	Aves (C)	Reptilia (D)
	Main Longitudinal Vessels			
1	Aorta and caudal artery	Continuous vessels located ventral to the axial skeleton, extending from the region of the heart to the tip of the tail. Caudal artery enclosed in the hemal channel.		
2	Aortic arches	Left aortic arch only.	Right aortic arch only.	One pair of aortic arches.
3	Carotid arteries	Various connections of internal and external carotids with aortic arch: innominate artery, common carotid artery, carotid trunk.	Internal and external carotids originate from common carotid arteries, which may be symmetrical, asymmetical, fused, or one may be obliterated.	Internal and external carotid arteries originate from common carotids. Many Serpentes: Only one common carotid. Crocodylia: Carotid duct absent.
4	Posterior cardinal veins	In all embryos, two posterior cardinal veins are present, being continuous with the caudal vein. No renal portal system. Posterior cardinals obliterated and replaced by supracardinal derivatives, the azygos and hemiazygos veins. Posterior vena cava is main trunk vein.	Rudimentary caudal and renal portal veins. Renal veins join femoral and internal iliac veins in kidney, which in turn join to form posterior vena cava. Posterior vena cava receives hepatic vein; no posterior cardinal veins persist.	Formation of kidneys causes great changes in distribution of posterior cardinals (renal portal system). Sauria: Caudal vein empties into two renal portal veins. Two hepatic veins join posterior vena cava. Crocodylia: Posterior vena cava emerges as single vessel from kidneys.
5	Anterior cardinal veins	Two anterior venae cavae, each consisting of an anterior cardinal vein, inferior jugular vein, and subclavian vein. Primates, Carnivora: Section of left vein, located between heart and anastomosis, disappears. Ungulata: Right vena cava more prominent than left because blood passes from left into right by anastomosis. Rodentia, Insectivora: Innominate veins of equal size.	Two anterior venae cavae, each consisting of an anterior cardinal vein, vertebral vein, and subclavian vein. Right cardinal vein more prominent than left. Inferior jugular vein absent.	Sauria: Similar in structure to *Sphenodon*. *Sphenodon:* Two anterior cardinal veins (internal jugular veins). Inferior jugular veins (external) reduced and replaced by tracheal vein; these veins join subclavian vein to form anterior vena cava.
	Main Segmental Vessels[1]			
6	Dorsal segmental vessels	In each myoseptum, one artery and one vein are present. Tributaries are ventral medullary arteries and veins, and muscular arteries and veins.		Serpentes: Longitudinal dorsal vein present.
7	Dorsal rami			
8	Ventral rami	Segmental vessels run from the main longitudinal vessels (aorta, cardinal veins) in horizontal myoseptum and reach skin. Tributaries are muscular arteries and veins. Some segmental become intercostal arteries and veins that surpass main vessels in size. In region of paired limbs, segmental vessels become subclavian and iliac arteries and veins.		

/1/ In all embryos, dorsal, lateral, and ventral segmental arteries and veins are present. They persist at least

CIRCULATORY SYSTEM: VERTEBRATES

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VESSELS

Amphibia	Pisces and Chondrichthyes	Agnatha	
(E)	(F)	(G)	
Main Longitudinal Vessels			
Continuous vessels located ventral to the axial skeleton, extending from the region of the heart to the tip of the tail. Caudal artery enclosed in the hemal channel; aorta similarly enclosed in *Acipenser* (sturgeon) only.			1
One to four pair of aortic arches.	Mainly four to five epibranchial arteries. Dipnoi: Pulmonary arteries present.	Six, seven, or more epibranchial arteries.	2
Internal and external carotid arteries. Salientia: Carotid duct absent.	Internal carotid arteries.	Petromyzones: Internal carotid artery dorsal, external carotid artery ventral. Myxini: Internal and external carotid arteries.	3
In all embryos, two posterior cardinal veins are present, being continuous with the caudal vein. Formation of kidneys causes great changes in distribution of posterior cardinals (renal portal system).		Renal portal system absent. Petromyzones: Same as in embryo. Myxini: Same as in embryo, but right posterior cardinal vein much thinner than left.	4
Posterior cardinals rudimentary. Well-developed posterior vena cava drains kidneys. Caudata: Renal portal blood derived from iliac and caudal veins.	Pisces: Posterior cardinals often asymmetrical but receive renal and hepatic veins. Renal portal blood derived from caudal vein and/o[illegible]tal veins; caudal vein often leads [illegible] to posterior cardinal. Dipnoi: Caudal [illegible] renal portal veins, asymmetric posterior cardinal vein, and a posterior vena cava. Chondrichthyes: Caudal vein empties into renal portal veins; hepatic veins empty into posterior cardinal veins, which are sinus-like distentions.		
Salientia: Anterior cardinal veins (internal jugulars) and inferior jugular veins fuse into one short trunk on each side and enter sinus venosus by intermediation of anterior vena cava (cranial). Caudata: Two anterior cardinal veins (internal jugulars), two inferior jugular veins.	Pisces: Two cardinal veins. Mainly one internal jugular vein joining sinus venosus. Dipnoi: Two cardinal and two jugular veins. Chondrichthyes: Anterior cardinal veins (internal jugulars) are sinus-like distentions. Inferior jugular veins open into duct of Cuvier.	Petromyzones: Anterior cardinal veins unite to form common trunk and open into sinus venosus. Inferior jugular vein (ventral) present. Myxini: Left anterior cardinal vein (internal jugular) and inferior jugular vein (ventral) join sinus venosus. Right anterior cardinal vein opens into cor portale of liver.	5
Main Segmental Vessels[1]			
Arteries and veins alternate in successive segments; their dorsal tips join to form the longitudinal dorsal trunk, and may persist in adults. Tributaries of dorsal segmental vessels are ventral medullary arteries and veins, and muscular arteries and veins.			6
	Deep pinnal arteries and veins are segmental vessels, supplying dorsal fins.		7
Segmental vessels run from the main longitudinal vessels (aorta, cardinal veins) in horizontal myoseptum and reach skin. Tributaries are muscular arteries and veins. Some segmental become intercostal arteries and veins that surpass main vessels in size. In region of paired fins and limbs, segmental vessels become subclavian and iliac arteries and veins.			8

partially in adults and give rise to some longitudinal as well as other important stems.

continued

	Vessel	Mammalia	Aves	Reptilia
	(A)	(B)	(C)	(D)
	Main Segmental Vessels[1]			
	Dorsal segmental vessels			
9	Lateral cutaneous vein[3]			Sauria: Lateral cutaneous vein probably present in all species.
10	Abdominal vein[3]	Only anterior root of abdominal vein persists and is represented by umbilical vein in the embryo.		Abdominal vein, double or single, connects renal portal with hepatic portal system.
11	Epigastric arteries and veins[3]	Two distinct trunks running close to each other are located on the inner surface of the abdominal wall between longitudinal abdominal and segmental trunk muscles. Probably absent in birds.		
12	Lateral segmental vessels	Paired lateral vessels supply pronephros, mesonephros, and, when present, metanephros. Their number is much reduced in higher forms when forming renal and gonadal arteries.		
13	Ventral segmental vessels	In all embryos, ventral segmental vessels originate from main longitudinal vessels (aorta, caudal art[illegible] caudal vein). In trunk, only arteries (mesenteric) originate from main longitudinal vessels, and in tail both arteries and veins. Paired arteries frequently unite to form a single median vessel.		
14	Arteries	Celiac artery, anterior mesenteric artery (cranial or superior), posterior mesenteric artery (caudal or inferior).	Celiac artery, anterior mesenteric artery (superior), posterior mesenteric artery (inferior).	Serpentes: Many arteries (mesenteric) reach intestine from the aorta *(Boa)*. Sauria: Gastric, celiomesenteric, and posterior mesenteric arteries. Crocodylia: Gastroesophageal, celiomesenteric, and mesenteric arteries. *Sphenodon:* Gastric, celiac, common mesenteric (anterior), and posterior mesenteric arteries.
15	Veins	Subintestinal vein, which gets some blood directly from caudal vein, develops with invasion of intestine by ventral segmental arteries. Subintestinal vein is prominent vessel in embryonic fish and amphibians; less significant in birds and reptiles; remnants found in *Didelphis;* parallels ventral border of intestinal tube and enters right omphalomesenteric vein. Subintestinal and parts of right and left omphalomesenteric veins form the hepatic portal vein. Omphalomesenteric veins and umbilical vein participate in liver circulation; hepatic vein opens into posterior vena cava; subintestinal vein is incorporated into trunk of hepatic portal vein.		
	Vessels of the Forelimb			
16	Arteries	Right subclavian artery arises from left aortic arch, chiefly as innominate artery, and left subclavian directly from arch or truncus communis. Axillary artery, brachial artery, median artery (main vessel in most mammals), ulnar artery (main vessel in Prosimii), radial artery, interosseal artery (main vessel in *Ornithorhynchus)*. Metacarpal arteries, dorsal and volar digital arteries.	Subclavian artery, with carotid artery, originates from right aortic arch (innominate artery). Axillary, brachial, ulnar (main vessel), interosseal, radial, and ulnar nerve arteries; metacarpal and digital arteries.	Sauria: Both subclavian arteries arise from right aortic arch. Axillary, brachial, interosseal (main vessel), ulnar, radial, and median arteries; metacarpal and digital arteries. Chelonia: Subclavian artery, with carotid artery, originates from innominate artery. Brachial artery replaced by lateral brachial artery. Two arterial arches of hand, dorsal and volar.

/1/ In all embryos, dorsal, lateral, and ventral segmental arteries and veins are present. They persist at least originating from ventral rami of dorsal segmental vessels.

CIRCULATORY SYSTEM: VERTEBRATES

VESSELS

Amphibia	Pisces and Chondrichthyes	Agnatha	
(E)	(F)	(G)	
Main Segmental Vessels[1]			
Gymnophiona, Caudata, Dipnoi, Chondrichthyes: Lateral cutaneous vein in lateral line groove, below skin from tail to region of forelimb. Originates from end tips of lateral segmental veins.			9
Salientia: Great and small cutaneous vein.			
Extends from region of cloaca to shoulder girdle, where it merges into sinus venosus or into hepatic portal system.			10
Salientia, Caudata: A single median, ventral abdominal vein.	Chondrichthyes: Two lateral abdominal veins, one on each side of body wall.		
Two distinct trunks running close to each other are located on the inner surface of the abdominal wall between longitudinal abdominal and segmental trunk muscles.		Myxini: Netlike track.	11
Paired lateral vessels supply pronephros and mesonephros.			12
In all embryos, ventral segmental vessels originate from main longitudinal vessels (aorta, caudal artery, caudal vein). In trunk, only arteries (mesenteric) originate from main longitudinal vessels, and in tail both arteries and veins. Paired arteries frequently unite to form a single median vessel.			13
Salientia: Only celiomesenteric artery. Caudata: Celiac artery and about 13 mesenteric arteries, almost segmental in arrangement, distributed to intestine *(Siren)*. Segmental arteries fuse into complex vessels *(Menobranchus, Cryptobranchus, Salamandra)*.	Pisces: Mainly one celiomesenteric artery. Dipnoi: Celiac artery, two or three mesenteric arteries. Chondrichthyes: Celiac artery, two or three mesenteric arteries.	Petromyzones: Only one artery persists as celiomesenteric artery. Myxini: Mesenteric arteries (approximately 35 in number) distributed to intestine as segmental vessels.	14
Subintestinal vein, which gets some blood directly from caudal vein, develops with invasion of intestine by ventral segmental arteries. Subintestinal vein is prominent vessel in embryonic fish and amphibians; parallels ventral border of intestinal tube and enters right omphalomesenteric vein. Subintestinal and parts of right and left omphalomesenteric veins form the hepatic portal vein; vitelline vein (omphalomesenteric) may participate in liver circulation.			15
Hepatic vein opens into posterior vena cava. Subintestinal vein is incorporated in trunk of hepatic portal vein.	Hepatic vein opens directly into heart. Many Pisces (including Dipnoi), Chondrichthyes: Subintestinal vein well-developed, Absent in many Cyprinoidea.	Petromyzones: Subintestinal vein well-developed. Myxini: Subintestinal vein reduced.	
Vessels of the Forelimb			
Salientia: Subclavian arteries originate from aortic arch, brachial, and deep brachial arteries. Other vessels same as in Caudata. Caudata: Subclavian artery arises from median aorta. Brachial, interosseal (main vessel), radial (radiomarginal), and ulnar (ulnomarginal) arteries. Dorsal arterial arch of hand, metacarpal and digital arteries.	Pisces: Subclavian artery originates from median aorta. Basal arteries, interradial arteries. Chondrichthyes: Subclavian artery arises from median aorta. Lateral and medial pterygial artery, adradial arteries.	Forelimbs absent.	16

partially in adults and give rise to some longitudinal as well as other important stems. /2/ Longitudinal vessels

continued

	Vessel	Mammalia	Aves	Reptilia
	(A)	(B)	(C)	(D)
	Vessels of the Forelimb			
17	Veins	Comparative anatomy of these veins awaits revision: digital veins, metacarpal veins, volar and dorsal venous arch, basilic vein (ulnomarginal), cephalic vein (radiomarginal), ulnar vein, radial vein, medial vein, brachial vein, axillary vein, subclavian vein. (The above list valid for five-fingered appendage.)	Metacarpal veins; basilic vein (main vessel), ulnar vein, interosseal vein, radial vein (radiomarginal), brachial vein. Subclavian vein enters anterior vena cava.	Sauria: Digital veins, dorsal venous arch of hand, radial vein (main vessel, marginal radial vein in embryos), ulnar vein, interosseal vein, brachial vein and lateral brachial vein. Lateral cutaneous vein empties into axillary vein. Subclavian vein enters internal jugular vein. *Alligator, Emys:* Only one brachial vein.

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	Component	Mammalia	Aves	Reptilia
	(A)	(B)	(C)	(D)
1	Lymph hearts	Absent even in embryos.	In all embryos only one pair of posterior hearts, located in region between pelvis and femur. Hearts persist in some adults *(Alca, Anser, Casuaris, Podiceps, Struthio).*	Only posterior hearts. Serpentes: Two elongated vesicles, each surrounded by bifurcated transverse processes of four-to-five caudal vertebrae. Sauria: Two ovoid vesicles attached to both ends of transverse process of first caudal vertebra. Crocodylia, Chelonia: Spherical in shape.
2	Lymph sacs (other than hearts), lymph sinuses	Jugular and iliac lymph sacs in embryos only.		Serpentes: Mandibular sinus. Sauria: Retrocardial, axillary, jugular, tracheal, and thyroidal sinuses. Crocodylia: Absent. Chelonia: Jugular cistern.
3	Lymph nodes	Many lymph nodes: approximately 465 in man, 300 in cattle, 60 in dog, 8,000 in horse.	Microscopically discernible nodes in walls of lymph vessels. Anseriformes: Two cervicothoracic and two lumbar lymph glands macroscopically visible.	Chelonia: Small nodes in lower eyelid.

/1/ Cole [7] and Favaro [8] regard these sacs as venous hearts.

CIRCULATORY SYSTEM: VERTEBRATES

VESSELS

Amphibia	Pisces and Chondrichthyes	Agnatha	
(E)	(F)	(G)	
Vessels of the Forelimb			
Salientia: Digital veins, dorsal venous arch of hand, ulnar vein (ulnomarginal), radial vein (radiomarginal), interosseal vein. Brachial vein and great cutaneous vein unite to join subclavian vein which enters anterior vena cava (cranial). Deep brachial vein continues as subscapular vein which, together with internal jugular vein, forms brachiocephalic vein. Caudata: Digital veins, interosseal vein (main vessel), ulnar vein (ulnomarginal), radial vein (radiomarginal), brachial vein. Subclavian vein, together with lateral cutaneous vein, enters sinus venosus.	Pisces: Interradial veins, basal vein. Subclavian vein enters duct of Cuvier or posterior cardinal vein. Left subclavian joins abdominal vein and epigastric vein, right subclavian joins only epigastric vein *(Salmo)*. Chondrichthyes: Adradial veins, lateral and medial pterygial vein. Subclavian vein fuses with epigastric vein and enters duct of Cuvier.	Forelimbs absent.	17

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LYMPHATICS

Amphibia	Pisces and Chondrichthyes	Agnatha	
(E)	(F)	(G)	
Gymnophiona: Approximately 100 spherical vesicles in trunk and tail, beneath skin in lateral line groove. Salientia: One pair of anterior and one-to-four pair of posterior hearts. Caudata: Ten to twenty rounded vesicles on each side of trunk, located as in Gymnophiona.	Pisces: Two elongated vesicles joined by a channel and located at base of tail. Vesicles not pulsating in ganoid fishes. Chondrichthyes: Absent.	Petromyzones: Absent. Myxini: One pair of pulsating sacs located in tail[1].	1
Salientia: In tadpoles, mandibular, circumoral, pericardial, and temporal sinuses; in adults, several subcutaneous sacs. Caudata: Orbital sinus, sinus lymphaticus cordis, axillary sinus in larvae only.	Pisces: Pectoral pinneal, orbital, cephalic, occipital, and lateral sinuses. Chondrichthyes: Absent.	Petromyzones: Supralabial, orbital, ocular ring, and deep labial sinuses. Myxini: Three subcutaneous sacs underlie entire skin.	2
			3

continued

	Component	Mammalia	Aves	Reptilia
	(A)	(B)	(C)	(D)
4	Subvertebral lymphatic trunks (thoracic duct)	One or two trunks associated with aorta and caudal artery.	Two trunks located on both sides of aorta.	Serpentes, Sauria: Sinus surrounds aorta. Crocodylia: Two slender trunks. Chelonia: Two trunks in tail, single in body cavity and bifurcated anteriorly.
5	Cisterna chyli in lumbar area	Always present. Great variation in shape and size.		Serpentes, Crocodylia: Absent. Sauria, Chelonia: Present.
6	Connections with veins	In most mammals thoracic duct connects with left anterior cardinal vein, in some with right, in few with both.	With anterior cardinal veins.	With anterior cardinal veins.
7	Jugular lymphatic trunk	Irregular lymph vessels join anterior cardinal veins separately or by way of subvertebral trunks.	Each of two trunks joins corresponding subvertebral trunk.	Sauri[illegible] wo trunks connected with subvertebral trunks by way of jugular sinus. Crocodylia: Two trunks enter corresponding anterior cardinal veins. Chelonia: Two trunks enter jugular cistern which connects both subvertebral trunks.
8	Lateral longitudinal lymphatic trunks	In adult, present only in tail. In embryos, transitory thoracic part observed.		Serpentes: Lateral trunk reaches maxillary sinus. Sauria: From tip of tail to forelimb. Caudal part enters lymph heart, thoracic part enters axillary sinus. Crocodylia: Only caudal part present. Chelonia: Thoracic part well-developed.
9	Longitudinal lymphatic trunks (other than lateral)			

Contributor: Grodziński, Z.

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CIRCULATORY SYSTEM: VERTEBRATES

LYMPHATICS

Amphibia	Pisces and Chondrichthyes	Agnatha	
(E)	(F)	(G)	
Gymnophiona: One sinus-like extended trunk accompanies aorta. Salientia: Two trunks. Caudata: One or two trunks.	Two slender trunks located on both sides of aorta and caudal artery.	Petromyzones: Unpaired sinus-like trunk beneath aorta and cardinal veins. Myxini: Two wide trunks located on both sides of aorta; fused into wide sinus in liver region.	4
Gymnophiona, Salientia: Absent. Caudata: Present. Extends to thoracic region.			5
Salientia: With anterior lymph hearts. Caudata: With anterior cardinal veins.	Pisces: With anterior cardinal veins. Chondrichthyes: With posterior cardinal vein at point where subclavian artery crosses.	Petromyzones: Numerous connections with both posterior cardinal veins. Myxini: With anterior cardinal vein.	6
Salientia: Two short trunks connecting head sinuses with anterior lymph hearts. Caudata: Two trunks connected with corresponding subvertebral trunks.	Pisces: Two sinus-like distended vessels connected with corresponding subvertebral trunks. Chondrichthyes: Two trunks connected with corresponding anterior cardinal veins.	Petromyzones: Seven peribranchial sinuses, each connected with anterior cardinal vein. Myxini: Absent.	7
Gymnophiona, Caudata: In lateral line groove from base of tail to head. Opens into lymph hearts. Salientia: In tadpoles: from base of tail to anterior lymph heart, disappearing during metamorphosis.	Pisces: Below skin in lateral line groove from base of tail fin to head; opens into some of head sinuses or directly into duct of Cuvier. Chondrichthyes: Absent.		8
Salientia: Dorsal and ventral trunks only in fin of tadpoles. Caudata: Dorsal trunk unpaired, located in dorsal midline of tail and body. Ventral trunk unpaired, located in ventral midline of tail. Abdominal trunk paired in wall of abdomen.	Pisces: Dorsal trunk unpaired, located in dorsal midline of tail and body, from base of tail fin to head; ventral trunk unpaired, located in ventral midline of tail and in middle of abdominal wall. Spinal trunk dorsal to spinal cord. Chondrichthyes: Absent.		9

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	Gland or Tissue	Mammalia	Aves	Reptilia	Amphibia
	(A)	(B)	(C)	(D)	(E)
	Hypophysis				
	Adenohypophysis				
1	Pars distalis	Situated anteriorly and ventrally ("anterior lobe" of older terminology) [18,20].	Large. Situated ventrally or anteroventrally to neurohypophysis. Histologically distinguishable into cephalic and caudal regions. [40]	Well-developed. Situated ventrally and often posteriorly. [40]	Situated at posterior end of gland [32].
2	Pars intermedia	Between pars distalis and neural lobe. Often separated from pars distalis by remains of hypophyseal cleft. Occasionally absent. [18,20]	Absent.	Variable in development, usually with hypophyseal cleft separating it from pars distalis [40].	Situated anterodorsally to pars distalis [32].
3	Pars tuberalis	Surrounds infundibular stem, forming bed for primary plexus of hypophyseal portal system which vascularizes pars distalis [18, 20].	Consists of (i) pars tuberalis proper, a layer of cells on the ventral surface of the diencephalon and within the pia mater; (ii) a portal zone of cell cords and blood vessels, connecting pars tuberalis proper with (iii) pars tuberalis interna which is fused with the pars distalis. [40]	Reduced or absent [40]. Serpentes: Absent [40]. Sauria: Distinguishable only as a few cells in floor of brain [40].	Salientia: Usually reduced (perhaps sometimes absent). Forms two small plates on ventral surface of tuber cinereum. [32] Caudata: Represented by lateral lobes connected with pars distalis [32].
4	Neurohypophysis	Divisible into two regions, pars nervosa and median eminence, each with separate vascularization. Pars nervosa usually globular; formed from distal extremity of infundibulum; may or may not contain an extension of the third ventricle. Median eminence is an ill-defined region of infundibular stalk on floor of diencephalon, usually anterior to pars nervosa and always connected to pars distalis by portal blood vessels. Both parts of neurohypophysis contain endings of neurosecretory neurones from the hypothalamus. [18,40]	Distinct neural lobe, or pars nervosa, lying posteriorly and carried by an infundibular stem. A median eminence develops from floor of third ventricle, or infundibular stem anterior to pars nervosa, from which it is not sharply delimited; covered by capillary net of hypophyseal portal system. [40]	Well-defined neural lobe [40]. Serpentes: Compact organ [40]. *Sphenodon*, some Sauria, Chelonia: Thin-walled sac [40]. A median eminence is differentiated out of infundibular floor. Ranges from a simple form, differing little from neural lobe, to a thickened structure with capillaries of the hypophyseal portal system buried in it. [18,40]	A true neural lobe, or pars nervosa, with independent blood supply, is present as a posterodorsal thickening of the infundibular process. Relatively large in terrestrial species, smaller in more aquatic ones. [18] *Rana:* A median eminence with portal vessels [18].

ENDOCRINE SYSTEM: VERTEBRATES

Pisces			Agnatha		
Crossopterygii	Neopterygii and Palaeopterygii	Chondrichthyes	Myxini	Petromyzones	
(F)	(G)	(H)	(I)	(J)	
Protopterus: Situated ventrally. Separated from pars intermedia by large hypophyseal cleft. [41] *Latimeria:* has form of elongated cord [30].	Probably represented by rostral zone and proximal zone of pars distalis. Rostral zone is follicular in lower forms such as *Acipenser, Amia,* and *Lepisosteus.* [32,33] *Polypterus:* Hypophyseal duct remains open in adult [32,33].	Probably represented by tonguelike rostral lobe; also by a ventral lobe, variable in shape and size, which is peculiar to the group. [10,33]	Rostral zone (irregular cell cords), histologically differentiated from proximal zone (broad cell cords). Both separated from brain by layer of connective tissue. [31,38]	Not divided into regions. Separated from brain by layer of connective tissue. May be penetrated by small diverticula from nasopharyngeal duct. [31,38]	1
Protopterus: Dorsal to hypophyseal cleft; tube-shaped lobules with wide cavities. Closely attached to infundibular process lying rostrally to pars intermedia. [41]	Probably represented by "pars intermedia," tissue most intimately associated with neurohypophysis [18,32,33].	Interdigitates with infundibular process to form neurointermediate lobe [10,33].	Probably represented by most posterior part of adenohypophysis. Long and thin, and in close contact with neurohypophysis along entire length. [31,38]	Not visibly differentiated.	2
Protopterus: Possibly represented by rostral part of pars distalis [41].	Probably not represented.	Not distinguishable.	Not distinguishable.	Not distinguishable.	3
Protopterus: Gives rise to distinctly paired infundibular process, as branches and diverticula of the hypothalamus that intermingle with lobules of the pars intermedia. Median eminence is believed to be represented by an area in the floor of the third ventricle, just rostral to the anterior tip of the adenohypophysis; surface is indented by capillaries that communicate with sinusoids of adjacent adenohypophysis. [41]	Extensions of the floor of the hypothalamus interdigitate closely with the pars intermedia. Contains ends of neurosecretory fibers and accumulated neurosecretion originating mainly in the nucleus preopticus. Also interdigitates with adenohypophysis to a lesser extent. [24,32,33]	Infundibular process interdigitates with pars intermedia. Diffuse structure formed by endings of neurosecretory fibers originating in nucleus preopticus. [10,33] Median eminence on ventral surface of hypothalamus, with portal vessels vascularizing pars distalis [29].	Formed by thickened floor of diencephalon, particularly posterior part [31,38].	Caudally-directed, saclike projection of the hypothalamus represents infundibular process; thin-walled and unpaired, with many terminations of neurosecretory fibers. No contact with adenohypophysis. Well-vascularized, with a folded surface. Contains neurosecretion. [31,38]	4

continued

	Gland or Tissue	Mammalia	Aves	Reptilia	Amphibia
	(A)	(B)	(C)	(D)	(E)
5	Thyroid	Two lateral lobes and a median isthmus; lateral lobes at sides of trachea, cranial ends at level of caudal edge of cricoid cartilage.	One pair of glands, situated at boundary of neck and thoracic cavity [7].	Single lobulate organ, lying close to trachea [9]. *Chrysemys:* Flattened mass ventral to truncus arteriosus [9].	Paired, widely separated lobes, closely associated with wings of hyoid cartilage (in almost all Amphibia).
6	Parathyroid	Usually two pairs, situated along dorsal-lateral border of the thyroid as anterior and posterior pairs. Accessory glands common along carotid arteries and in mediastinum. [19] Man: Two to six may be present. Anterior pair may be imbedded in thyroid. [19] Cat, dog: Anterior pair may be imbedded in thyroid [19]. Rat: Only posterior pair present. Visible on surface of thyroid. [19]	One or two pairs, developing from third and fourth branchial pouches. Situated posterior to thyroid glands. [7]	Usually two pairs, situated in neck; posterior and lateral to thyroid.	*Rana:* Two pairs, against jugular veins [13]. *Salamandra:* One pair of spherical bodies, derived from ventral ends of third and fourth hranchial clefts. Widely separated from thyroids; lateral to arterial arches. Absent in some perennibranchiates *(Ambystoma, Necturus)*. [13] Sauria: Situated at level of vagus ganglion [39].
7	Ultimobranchial bodies	Fused with thyroid tissue. Sometimes found aberrant in lateral neck tissues. [17]	Closely associated with, and may surround, parathyroid glands. Cell strands with some colloid-filled vesicles. [39]	Paired; groups of vesicles and strands, varying in position [39]. Serpentes: Situated against thyroid [39]. Reportedly absent in some snakes [17]. Sauria: Situated at level of vagus ganglion [39].	Gymnophiona, Salientia: Bilateral, at level of truncus arteriosus; vesicular. [13] *Salamandra:* Small single body near heart [13].
8	Adrenals	One pair, ovoid-shaped [23]. Eutheria: Situated immediately anterior to kidneys, with which adrenals may be in contact [23]. Eutheria, Metatheria: Adrenocortical tissue forms cortex, chromaffin tissue forms medulla [23]. Prototheria: Chromaffin tissue interdigitates with adrenocortical tissue [23].	One pair (occasionally fused), situated at anterior end of kidneys wholly or partly covered by gonads. Adrenocortical tissue forms anastomosing cords, with chromaffin tissue irregularly distributed in its meshes. [21]	One pair, elongated in shape. Adrenocortical tissue forms anastomosing cords; chromaffin tissue intermingled and also forming a peripheral layer. [23,40] Serpentes, Sauria: Anterior to kidneys [23, 40]. Crocodylia: Situated between, and anterior to, kidneys [23,40]. Chelonia: On ventral surface of kidneys. May fuse. [23,40]	*Salamandra:* Series of orange patches along ventromesial border of kidneys. May extend forward, in association with sympathetic ganglia, to subclavian artery. Brighter and more conspicuous in breeding season. [13,21] *Siren:* Situated between, and in front of, kidneys [13,21]. Chromaffin cells interspersed with cords of adrenocortical cells [13,21].

/1/ Corpuscles of Stannius, one or more of which lie in or on posterior kidney, were at one time regarded as

ENDOCRINE SYSTEM: VERTEBRATES

Pisces		Chondrichthyes	Agnatha		
Crossopterygii	Neopterygii and Palaeopterygii		Myxini	Petromyzones	
(F)	(G)	(H)	(I)	(J)	
	Diffuse follicles around ventral aorta [28]. *Scarus:* Follicles compact and encapsulated [28].	Compact organ lying at, or ventral to, anterior end of ventral aorta, between coracomandibular and coracohyoid muscles.	Elongated follicles extend from second to fifth branchial pouch, dorsal to medioventral cartilage of branchial basket [12].	Separate, large follicles scattered in loose connective tissue along most of ventral surface of pharynx [37].	5
	Reportedly absent.	Reportedly absent.	Reportedly absent.	Reportedly absent.	6
	Vesicular, glandlike bodies, often on left side only, or fused to median body, above pericardial wall. Parathyroid-like function has been suggested. [11,17,39]	Vesicles with colloid contents on left side only. Dorsal to pericardium (suprapericardial body). [8,39]	Reportedly absent [39].	Reportedly absent [39].	7
Exact limits of adrenocortical tissue doubtful. Probably present as small groups of cells between ventral margins of kidneys, and in walls of capillaries supplying posterior cardinal veins. [15,23] Chromaffin tissue present as groups of cells distributed along posterior cardinal veins. Also associated with intercostal arteries. [23]	Adrenocortical tissue present as areas of cells in the (usually lymphoid) pronephros. May be scattered *(Salmo)*, or arranged as layers of cells closely associated with cardinal veins. [1,23][1] Chromaffin tissue mainly in pronephros, as scattered cells or islets near or in walls of cardinal veins and their branches. [1,23]	Dogfish: Adrenocortical tissue present as elongated body between kidneys and close to cardinal vein, with additional small groups of cells anteriorly [21,23]. *Raja:* Adrenocortical tissue a horseshoe-shaped body, usually asymmetrical, with the two limbs extending anteriorly against inner sides of kidneys [21,23]. *Torpedo:* Adrenocortical tissue an oval body lying posteriorly on left kidney [21,23]. Chromaffin tissue present as paired series of suprarenal bodies along length of body cavity. Situated above cardinal veins and kidneys, or imbedded in kidneys. Variable shape, tending to be distributed in relation to segmental arteries. Some large bodies lie anteriorly. [21]	Adrenocortical tissue present as scattered islets of cells against ventral and lateral walls of cardinal veins in trunk and tail; also as groups of cells in pronephros and around kidney vessels. [16] Chromaffin tissue probably represented by groups of cells distributed along main arteries and veins in trunk [14].		8

adrenocortical tissue, but this now seems doubtful [17].

continued

	Gland or Tissue	Mammalia	Aves	Reptilia	Amphibia
	(A)	(B)	(C)	(D)	(E)
9	Pancreatic tissue	Islets of Langerhans; small masses of tissue in pancreas. Principal cell types are α and β.	Islets of Langerhans in pancreas. More α than β cells. [17]	Islets of Langerhans in pancreas. More α than β cells. [17] Serpentes: Large aggregations of islets macroscopically visible at splenic end [5].	Islet tissue distributed throughout organ, ranging from single cells in exocrine acini to groups of cells [4, 17]. Caudata: β cells predominate [17].
10	Gonadal tissue	In testis, consists of interstitial (Leydig) cells between seminiferous tubules [32]. In ovary, probably represented by theca interna of graafian follicle and/or by interstitial cells of stroma. Progesterone-secreting cells of corpus luteum derived from granulosa cells of follicle, with perhaps a contribution from theca interna. [32]	Interstitial cells in testis [7].	Interstitial cells between seminiferous tubules of testis [27].	Interstitial cells in testis, conspicuous at breeding season.
11	Urohypophysis (Urophysis)				

Contributors: (a) Barrington, E. J. W., (b) Gorbman, Aubrey.

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Pisces		Chondrichthyes	Agnatha		
Crossopterygii	Neopterygii and Palaeopterygii		Myxini	Petromyzones	
(F)	(G)	(H)	(I)	(J)	
	Organ usually diffuse. Islet tissue may be scattered but is often one large islet situated near spleen (*Lophius*).	Islet tissue not well-identified. *Carcharhinus, Mustelus, Dasyatis:* Islet cells form a second epithelial layer around duct cells of pancreas. [36] *Raja:* Solid cords of islet cells contiguous to ducts of pancreas [36]. *Squalus acanthias:* Small islands of solid cell cords which are frequently separated from duct system of pancreas [36].	Islet tissue probably represented in ammocoete larva by groups of cells in wall of intestine adjacent to bile duct, and in adult by groups of cell cords in anterior wall of intestine [2,6].	Islet tissue possibly represented by cluster of cell cords in wall of intestine around bile duct [3,6].	9
	Gasterosteus, Oncorhynchus: Typical interstitial cells between tubules of testis [25,26]. *Esox:* Lobule boundary cells at periphery of testis lobules [25,26]. *Salmo gairdneri:* Both above types of endocrine tissue present [34].	*Chimaera, Scyliorhynus:* Probably interstitial cells between tubules of testis [25].		Interstitial cells reported in testis.	10
	Neurosecretory cells at hind end of spinal cord [17,22,35].	Neurosecretory cells (Dahlgren cells) at hind end of spinal cord [17].			11

Biol. 19:45. [3] Barrington, E. J. W. 1945. Quart. J. Microscop. Sci. 85:391. [4] Barrington, E. J. W. 1951. and comparative endocrinology. Clarendon Press, Oxford. [7] Benoit, J. 1950. Traite Zool. 15:290. [8] Camp, Evennett, and C. K. Goddard. 1960. Symp. London Zool. Soc. 1:77. [11] Eggert, B. 1938. Endokrinologie 20:1. salamander. Clarendon Press, Oxford. [14] Gaskell, J. F. 1912. J. Physiol. (London) 44:59. [15] Gérard, P. H. A. Bern. 1962. A textbook of comparative endocrinology. J. Wiley, New York. [18] Green, J. D. 1951. Am. New York. v. 1, p. 255. [20] Harris, G. W. 1955. Neural control of the pituitary gland. E. Arnold, London. U. 1959. Anat. Record. 135:51. [23] Jones, I. C. 1957. The adrenal cortex. Cambridge Univ. Press, London. [26] Marshall, A. J., and B. Lofts. 1957. Quart. J. Microscop. Sci. 98:79. [27] Marshall, A. J., and F. M. Woolf. [30] Millot, J., and J. Anthony. 1955. Compt. Rend. 241:114. [31] Olsson, R. 1959. Z. Zellforsch. Mikroskop. London, v. 1, 2; Little and Brown, Boston, v. 3. [33] Pickford, G. E., and J. W. Atz. 1957. The physiology of the Serv. Fishery Bull. 58:9. [35] Sano, Y. 1961. Ergeb. Biol. 24:191. [36] Thomas, T. B. 1940. Anat. Record 76:1. 1959. Z. Zellforsch. Mikroskop. Anat. 49:605. [39] Watzka, M. 1933. Z. Mikroskop. Anat. Forsch. 34:485. Sweden. [41] Wingstrand, K. G. 1956. Dansk. Naturhist. Foren. Videnskab. Medd. 118:193.

42. COMPARATIVE ANATOMY OF

Names of bones are those used in mammalian anatomy. Alternate names used in human anatomical terminology
pn = prenasal; var = variable; inn = innominate; px = proximally; d = distally.

Part I. AXIAL

	Bone	Primates					Artiodactyla		Perissodactyla	Sirenia	Proboscidea
		Homo sapiens (man)	*Pan troglodytes* (chimpanzee)	*Macaca mulatta* (rhesus monkey)	*Alouatta balzebul* (howler monkey)	*Lemur macaco* (lemur)	*Bos taurus* (cattle)	*Sus scrofa* (swine)	*Equus caballus* (horse)	*Trichechus* spp. (manatee)	*Elephas maximus* (Asiatic elephant)
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
	Skull										
1	Occipital	1	1	1	1	1	1	1	1	1	1
2	Parietal	1 pr	1 pr	1 pr, f	1 pr, f	1 pr	1 pr, f	1 pr, f	1 pr	1 pr	1 pr
3	Ethmoid	1	1	1	1	1	1	1	1	1	1
4	Turbinal	2 pr	2 pr	2 pr	2 pr	2 pr	2 pr	2 pr	2 pr	1 pr	1+ pr, ru
5	Interparietal	0	0	0	0	0	0	0	0	0	0
6	Frontal	1 pr, f	1 pr, f	1 pr, f	1 pr, f	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr
7	Nasal	1 pr	1 pr, f	1 pr, f	1 pr	1 pr	1 pr	1 pr	1 pr	0 or ru	1 pr
8	Lacrimal	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	ru	1 pr
	Temporal										
9	Periotic (petrosal)	} f	} f	} f	} f	} f	} f	1 pr	} f	} 1 pr	} 1 pr
10	Tympanic							1 pr			
11	Squamosal							1 pr	1 pr	1 pr	1 pr
12	Premaxilla	} f	1 pr, f	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr
13	Maxilla		1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr
14	Zygomatic	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr
15	Vomer	1	1	1	1	1	1	1	1	1	1
16	Palatine	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	f[2]	1 pr
17	Mandible	1 pr, f	1 pr, f	1 pr, f	1 pr, f	1 pr, f	1 pr	1 pr, f	1 pr, f	1 pr	1 pr, f
	Hyoid										
18	Basi-	1	1	1	1	1	1	1	1	1	1
19	Stylo-	0	0	0	0	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr
20	Epi-	0	0	0	0	1 pr	1 pr	0	1 pr	0	0
21	Cerato-	0	0	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	0	0
22	Thyro-	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr
	Vertebrae										
23	Cervical	7	7	7	7	7	7	7	7	6	7
24	Thoracic	12	13	12-13	12-13	12	13-14	14-15	18-19	17-18	19-20
25	Lumbar	5	4	7	6	6	6	5-7	6	2	3-4
26	Sacral	5	4-5	3	3	3	5	4	5	1 ru	4
27	Caudal	4	4-5	20±	27±	25-29	16-21	20-26	15-21	25±	31±
	Vertebral Ribs										
28	"True" ribs	7 pr	7 pr	8 pr	5 pr	7 pr	7-8 pr	7 pr	8 pr	0 or 1 pr	} 19-20 pr
29	"False" ribs	5 pr	6 pr	4 pr	7-8 pr	5 pr	5-7 pr	7-8 pr	10-11 pr	16-18 pr	
	Sternum										
30	Manubrium	1	1	1	1	1	1	1	1	} 1	1
31	Sternebrae	1	1	5	4	4	5	4	5		
32	Xiphisternum	1	1	1	1	1	1	1	1		1
33	Sternal ribs										

/1/ The extreme diversification in the skeletal system of the Edentata has not been included. /2/ Fused with

Contributors: Moyer, Elizabeth K., and Kaliszewski, Barbara Freeman

(*Nomina Anatomica,* 1955) appear in parentheses in column A. ***Abbreviations:*** pr = pair; f = fused; ru = rudimentary;

SKELETON

Carnivora			Cetacea		Rodentia		Lagomorpha	Edentata[1]	Chiroptera	Insectivora	Marsupialia	Monotremata		
Canis familiaris (dog)	*Felis catus* (cat)	*Phoca vitulina* (harbor seal)	*Balaenoptera physalus* (finback whale)	*Phocaena phocaena* (harbor porpoise)	*Cavia tschudi pallidor* (guinea pig)	*Rattus norvegicus* (Norway rat)	*Lepus americanus virginianus* (varying hare)	*Dasypus novemcinctus* (nine-banded armadillo)	*Eptesicus fuscus* (big brown bat)	*Sorex cinereus* (gray shrew)	*Didelphis marsupialis virginiana* (Virginia opossum)	*Ornithorhynchus* spp. (platypus)	*Tachyglossus* spp. (spiny anteater)	
(L)	(M)	(N)	(O)	(P)	(Q)	(R)	(S)	(T)	(U)	(V)	(W)	(X)	(Y)	
Skull														
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr, f	1 pr, f	1 pr	1 pr, f	1 pr, f	2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	3
2 pr	2 pr	2 pr	ru	0	2 pr	2 pr	2 pr	2 pr	2 pr	2 pr	2 pr	2 pr	2 pr	4
1	1	1	0	1	0	1	0	1	0	0	0	0	0	5
1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr, f	1 pr, f	1 pr, f	6
1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr, pn	1 pr, f	7
1 pr	1 pr	1 pr	1 pr	0	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	8
f	f	f	1 pr	1 pr	1 pr	1 pr	1 pr	f	1 pr	1 pr	1 pr	1 pr	1 pr	9
									1 pr	1 pr	1 pr	1 pr	1 pr	10
			1 pr	1 pr	1 pr	1 pr	1 pr		1 pr	1 pr	1 pr	1 pr	1 pr	11
1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	0	1 pr	1 pr	1 pr	1 pr	12
1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	13
1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	0	1 pr	1 pr	1 pr	14
1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr, f	1 pr	16
1 pr	1 pr	1 pr	1 pr	1 pr, f	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	17
1	1	1	1	1	1	1	1	1	1	1	1	1	1	18
1 pr	1 pr	1 pr	1 pr	1 pr	0	0	0	1 pr	1 pr	1 pr	0	0	0	19
1 pr	1 pr	1 pr	0	0	0	0	0	1 pr	1 pr	1 pr	0	1 pr	1 pr	20
1 pr	1 pr	1 pr	0	0	0	0	0	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	21
1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	22
Vertebrae														
7	7	7	7 f	7 f	7	7	7	7, 2 + 3 f	7	7	7	7	7	23
13	13	14-15	14	13	13	13	12	10	11-12	13	13	17	16	24
7	7	5	15	17	5-6	6-7	7	4-5	5-6	6	6	2	3	25
3	2-3	4-5	0	0	2	3-4	2-3	7	3		2	2	3-4	26
var	18±	9-14	24±	25±	8±	27±	var	27±	9±		19-35	20-23	12-13	27
Vertebral Ribs														
9 pr	9 pr	10 pr	1 pr	4-6 pr[3]	6 pr	7 pr	7 pr	5 pr	7 pr	13 pr	7 pr	6 pr	6 pr	28
4 pr	4 pr	5 pr	13 pr	7-9 pr	7 pr	6 pr	5 pr	5 pr	4 pr		6 pr	11 pr	10 pr	29
Sternum														
1	1	1	1	1	1	1	1	1	1	1	1	1	1	30
8	6	6			3-4	3-5	3-4	4	f	5	4	3	3f	31
1	1	1			1	1	1	1		1	1	0	1	32
								4 pr	7 pr		7 pr	6 pr	6 pr	33

sphenoid. /3/ Ossified intermediate ribs are present at the ventral ends of the first six pair of vertebral ribs.

continued

42. COMPARATIVE ANATOMY OF

Part I. AXIAL

References: [1] Adams, L. A., and S. Eddy. 1949. Comparative Anatomy. J. Wiley, New York. pp. 132-241. [3] International Anatomical Nomenclature Committee. 1955. Nomina anatomica. Spottiswoode, Ballantyne; London. 1962. The vertebrate body. Ed. 3. W. B. Saunders, Philadelphia. [6] Simpson, G. G. 1945. Bull. Am. Museum Saunders, Philadelphia. pp. 20-253.

Part II. APPENDICULAR

	Bone	Primates					Artiodactyla		Perisso-dactyla	Sirenia	Probos-cidea
		Homo sapiens (man)	*Pan troglodytes* (chimpanzee)	*Macaca mulatta* (rhesus monkey)	*Alouatta balzebul* (howler monkey)	*Lemur macaco* (lemur)	*Bos taurus* (cattle)	*Sus scrofa* (swine)	*Equus caballus* (horse)	*Trichechus* spp. (manatee)	*Elephas maximus* (Asiatic elephant)
	(A)	(B)	C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
	Pectoral Girdle										
1	Interclavicle	0	0	0	0	0	0	0	0	0	0
2	Coracoid	0	0	0	0	0	0	0	0	0	0
3	Anterior	0	0	0	0	0	0	0	0	0	0
4	Clavicle	1 pr	1 pr	1 pr	1 pr	1 pr	0	0	0	0	0
5	Scapula	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr
	Upper Extremity[a]										
6	Humerus	1	1	1	1	1	1	1	1	1	1
7	Radius	1	1	1	1	1	1	1	1	} f, px	1
8	Ulna	1	1	1	1	1	ru	1	ru		1
9	Carpus										
10	Scaphoid	1	1	1	1	1	1	1	1	1	1
11	Lunate	1	1	1	1	1	1	1	1	1	1
12	Cuneiform (triquetral)	1	1	1	1	1	1	1	1	1	1
13	Pisiform	1	1	1	1	1	1	1	1	0	1
14	Centrale	0	0	1	1	0	0	0	0	0	0
15	Trapezium	1	1	1	1	1	0	0	0 or 1	1	1
16	Trapezoid	1	1	1	1	1	} 1	1	1	1	1
17	Magnum (capitate)	1	1	1	1	1		1	1	1	1
18	Unciform (hamate)	1	1	1	1	1	1	1	1	1	1
19	Metacarpus	5	5	5	5	5				5	5
20	1st						0	0	0		
21	2nd						ru	1	ru		
22	3rd						} 1	1	1		
23	4th							1	ru		
24	5th						ru	1	0		
	Phalanges										
25	1st digit	2	2	2	2	2	0	0	0	2	2
26	2nd digit	3	3	3	3	3	0	3	0	3	3
27	3rd digit	3	3	3	3	3	3	3	3	3	3
28	4th digit	3	3	3	3	3	3	3	0	3	3
29	5th digit	3	3	3	3	3	0	3	0	3	3

/1/ The extreme diversification in the skeletal system of the Edentata has not been included. /a/ Single extremity. maining four, varying numbers of phalanges become ossified.

THE SKELETAL SYSTEM: MAMMALS

SKELETON

[2] Flower, W. H. 1885. An introduction to the osteology of the Mammalia. Ed. 3. Macmillan, London. [4] Parker, T. J., and W. A. Haswell. 1940. A textbook of zoology. Ed. 6. Macmillan, London. [5] Romer, A. S. Nat. Hist. 85:1. [7] Sisson, S., and J. D. Grossman. 1953. The anatomy of the domestic animals. Ed. 4. W. B.

SKELETON

Carnivora			Cetacea		Rodentia		Lago-morpha	Eden-tata[1]	Chirop-tera	Insec-tivora	Marsu-pialia	Monotremata		
Canis familiaris (dog)	*Felis catus* (cat)	*Phoca vitulina* (harbor seal)	*Balaenoptera physalus* (finback whale)	*Phocaena phocaena* (harbor porpoise)	*Cavia tschudi pallidor* (guinea pig)	*Rattus norvegicus* (Norway rat)	*Lepus americanus virginianus* (varying hare)	*Dasypus novemcinctus* (nine-banded arma-dillo)	*Eptesicus fuscus* (big brown bat)	*Sorex cinereus* (gray shrew)	*Didelphis marsupialis virginiana* (Virginia opossum)	*Ornithorhynchus* spp. (platypus)	*Tachyglossus* spp. (spiny anteater)	
(L)	(M)	(N)	(O)	(P)	(Q)	(R)	(S)	(T)	(U)	(V)	(W)	(X)	(Y)	
Pectoral Girdle														
												1	1	1
0	0	0	0	0	0	0	0	0	0	0	0	1 pr	1 pr	2
0	0	0	0	0	0	0	0	0	0	0	0	1 pr	1 pr	3
ru	ru	0	0	0	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	4
1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	1 pr	5
Upper Extremity[2]														
1	1	1	1	1	1	1	1	1	1	1	1	1	1	6
1	1	1	1	1	1	1	1	1	1	1	1	1	1	7
1	1	1	1	1	1	1	1	1	ru or 0	1	1	1	1	8
			5[3]											9
}1	}1	}1		1	}1	}1	}1	1	}1	1	1	}1	}1	10
				1				1		1	1			11
1	1	1		1	1	1	1	1	1	1	1	1	1	12
1	1	1		0	1	1	1	1	1	1	1	1	1	13
0	0	0		0	0	0	1	0	0	0	0	0	0	14
1	1	1		0	1	1	1	1	1	1	1	1	1	15
1	1	1		1	1	1	1	1	1	1	1	1	1	16
1	1	1		0 or 1	1	1	1	1	1	1	1	1	1	17
1	1	1		1	1	1	1	1	1	1	1	1	1	18
		5		5	5		5	5	5	5	5	5	5	19
ru	ru		0			ru								20
1	1		1			1								21
1	1		1			1								22
1	1		1			1								23
1	1		1			1								24
2	2	2	0	ru[4]	2	2	2	2	2	2	2	2	2	25
3	3	3	3		3	3	3	3	2	3	3	3	3	26
3	3	3	5		3	3	3	3	3	3	3	3	3	27
3	3	3	5		3	3	3	3	2	3	3	3	3	28
3	3	3	3		3	3	3	3	2	3	3	3	3	29

/3/ Homologies difficult. /4/ *P. phocaena* has five digits. The first is rudimentary and cartilaginous. In the re-

continued

	Bone	Primates					Artiodactyla		Perissodactyla	Sirenia	Proboscidea
		Homo sapiens (man)	*Pan troglodytes* (chimpanzee)	*Macaca mulatta* (rhesus monkey)	*Alouatta balzebul* (howler monkey)	*Lemur macaco* (lemur)	*Bos taurus* (cattle)	*Sus scrofa* (swine)	*Equus caballus* (horse)	*Trichechus* spp. (manatee)	*Elephas maximus* (Asiatic elephant)
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
	Pelvic Girdle										
30	Epipubic	0	0	0	0	0	0	0	0	0	0
31	Ilium									ru	
32	Ischium	}1 pr, inn	}1 pr, inn	}1 pr, inn	}1 pr, inn	}1 pr, inn	}1 pr, inn	}1 pr, inn	}1 pr, inn	0	}1 pr, inn
33	Pubis									0	
	Lower Extremity[2]										
34	Femur	1	1	1	1	1	1	1	1	0	1
35	Patella	1	1		1	1	1	1	1	0	1
36	Tibia	1	1	1	1	1	1	1	1	0	1
37	Fibula	1	1	1	1	1	ru	1	ru	0	1
	Tarsus										
38	Astragalus (talus)	1	1	1	1	1	1	1	1	0	1
39	Calcaneus	1	1	1	1	1	1	1	1	0	1
40	Navicular	1	1	1	1	1		1	1	0	1
	Cuneiform										
41	Internal	1	1	1	1	1	1	1	}1	0	1
42	Middle	1	1	1	1	1	}1 }1	1		0	1
43	External	1	1	1	1	1		1	1	0	1
44	Cuboid	1	1	1	1	1		1	1	0	1
45	Metatarsus	5	5	5	5	5				0	5
46	1st						0	0	0		
47	2nd						0	1	ru		
48	3rd						}1	1	1		
49	4th							1	ru		
50	5th						0	1	0		
	Phalanges										
51	1st digit	2	2	2	2	2	0	0	0	0	1
52	2nd digit	3	3	3	3	3	0	3	0	0	3
53	3rd digit	3	3	3	3	3	3	3	3	0	3
54	4th digit	3	3	3	3	3	3	3	0	0	3
55	5th digit	3	3	3	3	3	0	3	0	0	1

/1/ The extreme diversification in the skeletal system of the Edentata has not been included. /2/ Single extremity.

Contributors: Moyer, Elizabeth K., and Kaliszewski, Barbara Freeman

References: [1] Adams, L. A., and S. Eddy. 1949. Comparative Anatomy. J. Wiley, New York. pp. 132-241. [3] International Anatomical Nomenclature Committee. 1955. Nomina anatomica. Spottiswoode, Ballantyne; London. 1962. The vertebrate body. Ed. 3. W. B. Saunders, Philadelphia. [6] Simpson, G. G. 1945. Bull. Am. Museum Saunders, Philadelphia. pp. 20-253.

THE SKELETAL SYSTEM: MAMMALS

SKELETON

Carnivora			Cetacea		Rodentia		Lagomorpha	Edentata[1]	Chiroptera	Insectivora	Marsupialia	Monotremata		
Canis familiaris (dog)	*Felis catus* (cat)	*Phoca vitulina* (harbor seal)	*Balaenoptera physalus* (finback whale)	*Phocaena phocaena* (harbor porpoise)	*Cavia tschudi pallidor* (guinea pig)	*Rattus norvegicus* (Norway rat)	*Lepus americanus virginianus* (varying hare)	*Dasypus novemcinctus* (nine-banded armadillo)	*Eptesicus fuscus* (big brown bat)	*Sorex cinereus* (gray shrew)	*Didelphis marsupialis virginiana* (Virginia opossum)	*Ornithorhynchus* spp. (platypus)	*Tachyglossus* spp. (spiny anteater)	
(L)	(M)	(N)	(O)	(P)	(Q)	(R)	(S)	(T)	(U)	(V)	(W)	(X)	(Y)	
Pelvic Girdle														
0	0	0	0	0	0	0	0	0	0	0	1 pr	1 pr	1 pr	30
1 pr, inn	1 pr, inn	1 pr, inn	0	0	1 pr, inn	1 pr, inn	1 pr, inn	f[5], inn	1 pr, inn	1 pr, inn	1 pr, inn	1 pr, inn	1 pr, inn	31
			ru	ru										32
			0	0										33
Lower Extremity[2]														
1	1	1	0	0	1	1	1	1	1	1	1	1	1	34
1	1	1	0	0	1	1	1	1	1	1	0	1	1	35
f, d?	1	f, px	0	0	1	1	1	f, px	1	1	1	1	1	36
	1		0	0	1	1	1		1	1	1	1	1	37
1	1	1	0	0	1	1	1	1	1	1	1	1	1	38
1	1	1	0	0	1	1	1	1	1	1	1	1	1	39
1	1	1	0	0	1	1	1	1	1	1	1	1	1	40
1	1	1	0	0	1	1	1	1	1	1	1	1	1	41
1	1	1	0	0	1	1	1	1	1	1	1	1	1	42
1	1	1	0	0	1	1	1 or 0	1	1	1	1	1	1	43
1	1	1	0	0	1	1	1	1	1	1	1	1	1	44
		5	0	0	5	5		5	5	5	5	5	5	45
ru	ru						0							46
1	1						1							47
1	1						1							48
1	1						1							49
1	1						1							50
ru	ru	2	0	0	2	2	0	2	2	2	2	2	2	51
3	3	3	0	0	3	3	3	3	3	3	3	3	3	52
3	3	3	0	0	3	3	3	3	3	3	3	3	3	53
3	3	3	0	0	3	3	3	3	3	3	3	3	3	54
3	3	3	0	0	3	3	3	3	3	3	3	3	3	55

/5/ Fused with sacrum.

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V. NUTRITION AND DIGESTION

43. NUTRIENTS: CHEMICAL ELEMENTS

Accumulation in the tissues of an organism is not alone sufficient evidence that an element is required. *Abbreviations:* Capital letters indicate data are pertinent to all organisms studied; lower case letters and symbols indicate data apply to one or more species or strains, but not to all forms studied. R and r = required; R̸ = not required; u= = utilized as effectively as, replaces wholly, or is interchangeable with, another element; u< = can partially replace, or spare the use of, another element; s = stimulates growth or other processes; a = accumulates in the tissues; c = commonly present at similar concentrations in the food and tissues, but requirement is uncertain.

	Nutrient (Symbol)	Vertebrata	Invertebrata			Phytoflagellata (green)[2]	Algae	Bacteriophyta	Fungi		Spermatophyta
			Insecta	Other	Protozoa[1]				Saccharomycetaceae	Other	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
1	Aluminum (Al)	R̸	R̸	....	R̸	R̸	R̸	R̸, u<[3]	R̸	R̸, s	r, s, a
2	Arsenic (As)	R̸	R̸	a	R̸	R̸	R̸	R̸	R̸	R̸	R̸
3	Boron (B)	R̸	R̸	R̸	R̸	r?	r	r	R̸	R̸, r?	R
4	Bromine (Br)	u<	R̸	r?[4], a?	R̸	R̸	R̸, a	R̸	R̸	R̸	R̸
5	Calcium (Ca)	R	r, c	r	R	r	R	r, s	r, u=	r, s, a	R
6	Carbon (C)[5]	R	R	R	R	R	R	R	R	R	R
7	Chlorine (Cl)	R	r, c	r	R̸	R̸	a	R̸	R̸	R̸	r, s
8	Chromium (Cr)	r?	R̸	....	R̸	R̸	R̸	u=[6]	R̸	r, s	R̸
9	Cobalt (Co)	r	r?, s?	....	r	r	r	r	u=[7]	r, a	r
10	Copper (Cu)	r	r, c	r	r	...	r	r, u<[3]	r	R	R
11	Fluorine (F)	R̸, s	R̸	a	R̸	R̸	R̸	R̸	R̸	R̸	R̸, a
12	Gallium (Ga)	R̸	R̸	R̸	R̸	R̸	R̸	R̸	R̸	r, s	r
13	Hydrogen (H)[5]	R	R	R	R	R	R	R	R	R	R
14	Iodine (I)	R	R̸	r?, a	R̸	R̸	R̸, a	R̸, s	R̸, s	R̸	R̸, s
15	Iron (Fe)	R	r	r	R	R	R	r, u<[3]	R	R	R
16	Magnesium (Mg)	R	r	R	R	R	R	r	R	R	R
17	Manganese (Mn)	R	r, c, a	r[8]	r	r	r	r, u=	r, u=[7]	R, u<	R
18	Molybdenum (Mo)	r[9]	......	....	R̸	R̸	r[10]	r[10]	r	r[10], s	R, a
19	Nitrogen (N)[5]	R	R	R	R	R	R	R	R	R	R
20	Oxygen (O)[5]	R	R	R	R	R	R	R	R	R	R
21	Phosphorus (P)[5]	R	R	R	R	R	R	R	R	R	R
22	Potassium (K)	R	r, c, a	R	R	R	R, a	r	r	r	R
23	Rubidium (Rb)	R̸	R̸	....	R̸	R̸	R̸	u=[11]	R̸	R̸	R̸
24	Selenium (Se)	r	R̸	....	R̸	R̸	R̸	R̸	R̸	R̸	R̸, a
25	Silicon (Si)	R̸	R̸	r	r	r	r	R̸	R̸	R̸	r
26	Sodium (Na)	R	r?, c	....	r	R̸	r, a	r	R̸	R̸	r?, s, a
27	Strontium (Sr)	u<	R̸	....	R̸	R̸	R̸, u=	u=[12]	R̸	s, u<	R̸
28	Sulfur (S)[5]	R	R	R	R	R	R	R	R	R	R
29	Tungsten (W)	R̸	R̸	....	R̸	R̸	R̸	R̸	R̸	s	R̸
30	Vanadium (V)	R̸	R̸	r[13]	R̸, s?	R̸	r	u<[14]	R̸	R̸, s	R̸
31	Zinc (Zn)	R	r	r?, a	r	r	r	r, u=	r	r, s	R
	Reference	1,4,9,11,15, 18,21,25,30, 35,37-39,41, 42,46-48,52, 53,56	11,19, 27,28, 58	3, 6, 7, 11,14, 20,25, 26	10,11,22, 29,36	10,11,22, 29,36	8,11, 22,33, 49	11,17,43- 45,50,54, 55	5,11,13,44, 45,54,57	5,11, 12,16, 24,34, 44,45, 51,54	2,5,11,23, 26,31,32, 35,40,54

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /3/ Replaces or spares manganese or chromium in *Aerobacter aerogenes*. /4/ Occurs as dibromotyrosine in scleroprotein of certain corals. /5/ Universal constituent of protoplasm. /6/ Replaces, or is interchangeable with, manganese in *Aerobacter aerogenes*. /7/ Replaces, or is interchangeable with, calcium in yeast cocarboxylase. /8/ In blood respiratory pigment of *Pinna squamosa* (mollusk). /9/ Xanthine oxidase factor. /10/ Required for NO_3^- utilization by some fungi and some algae; required for nitrogen fixation by some bacteria and algae. /11/ Replaces, or is interchangeable with, calcium in some bacteria. /12/ Replaces, or is interchangeable with, calcium in *Azotobacter*. /13/ In blood pigment of certain tunicates (Chordata). /14/ Replaces or spares molybdenum in nitrogen fixation.

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44. NUTRIENTS: LIPIDS

Abbreviations: Capital letters indicate data are pertinent to all organisms studied; lower case letters and symbols indicate data apply to one or more species, or strains, but not to all forms studied. R and r = required; R̸ = not required; rm = required by one or more mutants; u = utilized; u= = utilized as effectively as a related substance; s = stimulates growth or other processes; i = inhibits growth or other processes.

	Nutrient	Vertebrata	Invertebrata		Phytoflagellata (green)[2]	Algae	Bacteriophyta	Fungi		Spermatophyta
			Insecta	Protozoa[1]				Saccharomycetaceae	Other	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Sterols									
1	Cholesterol	R̸	R[3]	r[4]	R̸	R̸	u	u	r[5], s	R̸
2	7-Dehydrocholesterol	u	u=	R̸, u=[6]	R̸	R̸	R̸	R̸	r[5]	R̸
3	Ergostanol acetate	s[7]	....	R̸, u=[6]	R̸	R̸	R̸	R̸	R̸	R̸
4	Ergosterol	u	u=	R, u=[6]	R̸	R̸	R̸	u, s	s	R̸
5	Stigmasterol	R̸, s	u=	r[8]	R̸	R̸	R̸	R̸	r[5]	R̸
	Long-Chain Fatty Acids and Their Derivatives									
6	Arachidonic acid	r, u=	s	.....	R̸	R̸	.....	R̸	....	R̸
7	Linoleic acid	r, u=	r	u=	R̸	R̸	s, i	R̸	r, rm	R̸
8	Linolenic acid	r, u=	u=	.....	R̸	R̸	.....	R̸	r	R̸
9	Oleic acid	R̸	r	r, s, i	R̸	R̸	r, s, i	R̸	r, rm, s	R̸
10	Palmitic acid	....	....	r[9]	...	...	R	...	....	...
11	Myrj G 2144[10]	R̸	R̸	R̸, s	R̸	R̸	R̸	R̸	R̸	R̸
12	Tween 80, 85[11]	R̸	R̸	R̸, s	R̸	R̸	R̸, s, i	R̸	R̸, s	R̸
	Phospholipids									
13	Lecithin[12]	R̸	u=, s	s	R̸	R̸	R̸	R̸	R̸	R̸
	Reference	7,14,21	5,9,27	2,6,12,13, 17,22,26	2,6,13,17, 18	1,11,18, 24	4,8,19,20, 25,26	4,8,19,25, 26	3,4,8,10, 19,25,26	15,16,23

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /3/ Several insect species utilize various sterols as effectively as cholesterol. /4/ Required by various *Trichomonas* species. /5/ Required by *Labyrinthula vitella pacifica* only, which also requires fucosterol, campesterol, β-sitosterol, clionosterol, brassicasterol, and poriferasterol. /6/ Utilized in place of cholesterol by *Trichomonas*. /7/ Relieves stiffness syndrome of guinea pig. /8/ Required by *Paramecium aurelia*; the organism's requirement for sitosterol has also been noted. /9/ Required by *Trichomonas gallinae*. /10/ A synthetic detergent (polyoxalkaline derivative of oleic acid). /11/ Synthetic detergents (sorbitan esters of fatty acids, e.g., oleic). /12/ A poorly defined, complex mixture of di-esters of α-glycerophosphoryl choline, with many unsaturated fatty acids and other substances (especially amino acids).

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45. NUTRIENTS: PROTEINS, PEPTIDES, AND AMINO ACIDS

Amino acids not known to be required from the environment have been omitted (e.g., hydroxyproline, iodogorgoic acid, norleucine, ornithine, thyroxine). No distinction has been made between dextro- and levo-isomers, although the levo-isomers are usually nutritionally superior. In most studies with multicellular animals, microorganisms were present and in some instances supplied one or more amino acids. When requirement and utilization are noted together, at least one member of the group of organisms requires the amino acid specifically for energy or synthesis of other compounds, and other members, although not requiring it, utilize it as a general nitrogen source. *Abbreviations:* Capital letters indicate data are pertinent to all organisms studied; lower case letters and symbols indicate data apply to one or more species, or strains, but not to all forms studied. R and r = required; rm = required by one or more mutants; R̸ = not required; U and u = utilized as a source of nitrogen and/or carbon although not a specific requirement; u= = replaces effectively one or more of the other amino acids, one of the interchangeable series being required in the diet; u̸ = not utilized; s = stimulates growth or other processes; * = serves as a complete nitrogen source; ** = serves as the simplest complete nitrogen source.

	Nutrient	Vertebrata	Invertebrata: Insecta	Invertebrata: Protozoa[1]	Phytoflagellata (green)[2]	Algae	Bacteriophyta	Fungi: Saccharomycetaceae	Fungi: Other	Spermatophyta
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
1	Organic nitrogen (per se)	R, U*	R, U*	r, U*	r, u*	R̸, u*	r, u*[3]	r, rm, u*[3]	r, rm, u*[3]	R̸, u*
2	Proteins (per se)	R̸[4], s, U*	R̸[4], s, U*	r[5], u*	u	R̸	R̸, u*	R̸, u*	R̸, u*	R̸
3	Polypeptides[6], peptones	R̸, U	R̸	r, u*	u*[7]	R̸, u*	r, u*[8]	R̸, u*	R̸, u*	R̸, u*
4	Amino acids	R, U**	R, U**	r[9], u*	r, u=[7], u*[10]	R̸, u*[11]	r[12], rm, u*	rm, u*[13]	r, rm, u*	R̸, u*[14]
5	Alanine	R̸, U	r, u=	u	R̸, u*	R̸, u*	r, u*	u*	u*, u=[15]	R̸, u*
6	Arginine	r[16], U	R[17]	r, s, u	R̸, u*	R̸, u*	r, rm, u*	rm, u*	r, rm, u*	R̸, u*
7	Aspartic acid	R̸, U	r[18], u=	u, s	r, u*	R̸, u*	r, u*	u*	u*, u=[15]	R̸, u*
8	Citrulline	R̸, u=, U	u, u=[17]	u	....	R̸	r, u*	....	rm, u*	R̸
9	Cysteine	R̸, U	r, u	u	....	R̸, u*	r, u*	u*	r, rm, u*	R̸, u*
10	Cystine	R̸, U	r[19], u=	u	....	R̸	r, rm, u*	u*	rm, u*	R̸, u*
11	Glutamic acid	s, U	r[18]	u, s	R̸, u*	R̸, u*	r, u*	u*	r, rm, u=[15], u*	R̸, u*
12	Glycine	r[20], U	r	r, u	R̸, u*	R̸, u*	r, u*	u*	rm, u*	R̸, u*

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /3/ Most species grow better on organic than on inorganic nitrogen. /4/ On the assumption that suitable amino acid combinations can replace complete proteins. /5/ Many species require living prey. /6/ *See* strepogenin (Table 48). /7/ Photoautotrophs, growing in the dark, require polypeptides, peptones, or amino acids. /8/ Some bacteria directly assimilate entire peptides, polypeptides, and low-molecular-weight proteins. /9/ *Glaucoma scintillans, Herpetomonas culicidarum, Tetrahymena geleii,* and *Tritrichomonas foetus* require arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, tryptophan, and valine; in addition, *G. scintillans* and *T. foetus* require glycine, proline, serine, and threonine, and *H. culicidarum* requires tyrosine. *Paramecium aurelia* requires arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, serine, threonine, tryptophan, and tyrosine. *Trichomonas gallinae* requires proline. *Tetrahymena geleii* needs no other carbon source. /10/ Various species and varieties differ markedly in utilization. /11/ Based mainly on *Chlorella pyrenoidosa.* /12/ Species differ widely in requirement. /13/ Amino acid mixtures are superior to NH_4^+ as a nitrogen source for some fungi (e.g., *Saccharomyces cerevisiae, S. carlsbergensis*). /14/ Several tested intact plants (tomato, tobacco, clover, pea, orchid embryo, young orchid) grew on single amino acids as the sole nitrogen source. Growth attained on some amino acids is superior to that achieved with NH_4^+ or NO_3^- as the nitrogen source; on other amino acids the effect is inferior. Some plants grow less well on amino acids than on inorganic nitrogen. Species differ markedly in amino acid utilization. /15/ Interchangeable for a *Neurospora* mutant. /16/ Required by rat and chicken. /17/ Arginine and citrulline are interchangeable for some insects; citrulline can partly replace arginine in *Drosophila melanogaster.* /18/ *Phormia regina* seems to require aspartic acid or glutamic acid, but not both. /19/ Some species apparently require either cystine or methionine, but not both, and proline. *Blattella germanica* requires neither cystine nor methionine in the presence of inorganic sulfates; threonine and tryptophan possibly are not required. /20/ Required by chick for rapid growth.

continued

45. NUTRIENTS: PROTEINS, PEPTIDES, AND AMINO ACIDS

	Nutrient	Vertebrata	Invertebrata		Phytoflagellata (green)[2]	Algae	Bacteriophyta	Fungi		Spermatophyta
			Insecta	Protozoa[1]				Saccharomycetaceae	Other	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Amino acids									
13	Histidine	R[21]	R	r, s, u	r, u*	Ɍ, u*	r, rm, u*	r, u*	r, rm, u*, s	Ɍ, u*
14	Isoleucine	R	R	r, u	....	Ɍ, u*	r, rm, u*	rm, u*	rm, u*	Ɍ, u*
15	Leucine	R	R, ʉ	r, u	Ɍ, u*	Ɍ, u̸	r, rm, u*	rm, u*	r, rm, u*	Ɍ, u*
16	Lysine	R	R	r, u	Ɍ, u*	Ɍ, u̸	r, rm, u*	u*	rm, u*, s	Ɍ, u*
17	Methionine	R[22]	R[19]	r, u	r	Ɍ, u̸	r, rm, u*	r, u*	r, rm, u*	Ɍ, u*
18	Phenylalanine	R[22]	R, ʉ	r, u	Ɍ, u*	Ɍ, u̸	r, rm, u*	rm, u*	rm, u*, s	Ɍ, u*
19	Proline	r, U	r[19]	r, u	Ɍ, u*	Ɍ, u̸	r, u*	u*	rm, u*, s	Ɍ, u*
20	Serine	Ɍ, U	r	r, s, u	Ɍ, u*	Ɍ, u̸	r, u*	u*	rm, u*	Ɍ, u*
21	Threonine	R	R[19], ʉ	r, u	....	Ɍ, u̸	r, u*	u*	rm, u*	Ɍ, u*
22	Tryptophan[23]	R	R[19], s, ʉ	r, u	Ɍ, u̸	Ɍ, u*	r, rm, u*	u*	r, rm, u*, s	Ɍ, u*
23	Tyrosine	Ɍ, U	ʉ[24]	r, u	Ɍ, u̸	......	r, rm, u*	u*	rm, u*, s	Ɍ, u*
24	Valine	R	R, ʉ	r, s, u	Ɍ, u*	Ɍ, u*	r, rm, u*	u*	rm, u*	Ɍ, u*
	Reference	1,5,11, 28,34, 39,44, 45,67, 80,95	36,48, 49,96	10,19,27, 41-43,51, 52,58,59, 69,75,76, 81,92	10,19,21-23,40-42, 57-59,69, 79,83,92	3,7,9,31, 55,58-60,69, 71,72, 77,83	14,20,74, 84,87,94	8,16-18,24-26, 29,30,37,38, 46,47,53,54, 61-66,70,74, 78,87,90,91,94	4,12,13,32, 33,46,56,74, 87,89,94	2,6,15, 35,50,68, 73,82,85, 86,88,93

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /19/ Some species apparently require either cystine or methionine, but not both, and proline. *Blattella germanica* requires neither cystine nor methionine in the presence of inorganic sulfates; threonine and tryptophan possibly are not required. /21/ Histidine is not required to maintain nitrogen balance in adult man. /22/ The amount of methionine required by man depends on the amount of cystine in the diet, and the amount of phenylalanine required depends on the amount of tyrosine in the diet. /23/ Precursor of niacin; spares niacin for some organisms. /24/ May replace phenylalanine in certain insects but not in others.

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46. NUTRIENTS: PURINES AND PYRIMIDINES

Purine and pyrimidine compounds are essential components of the nucleic acids. Inability to synthesize these compounds makes it necessary for many organisms to obtain them from the environment or diet. For some organisms the requirement is for a specific compound, or compounds; for others any one of an interchangeable series of compounds satisfies the need. *Abbreviations:* Capital letter indicates data are pertinent to all organisms studied; lower case letters and symbols indicate data apply to one or more species, or strains, but not to all forms studied. R̸ = not required; r = required; rm = required by one or more mutants; u = utilized; u̸ = not utilized; u= = utilized as effectively as, or is interchangeable with, one or more related compounds, the presence of at least one of the series being required; u< = partially replaces, or spares the use of, one or more required, or interchangeably required, compounds; s = stimulates growth or other processes; i = inhibits growth or other processes.

	Nutrient	Vertebrata	Invertebrata		Phytoflagellata (green)[2]	Algae	Bacteriophyta	Fungi		Spermatophyta
			Insecta	Protozoa[1]				Saccharomycetaceae	Other	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
1	Purine compounds	R̸, s	r	r, s	R̸	R̸	r, s, u	s, u	rm, s, u	R̸
2	Adenine	R̸, s	r, s	r?, u<[3]	R̸, u<[4]	R̸	u=[5]	r[6]	r, rm, u, s	R̸
3	Adenosine	R̸	u=, s	R̸, u<[3]	R̸	R̸	u=[5]	R̸	R̸, u	R̸
4	Adenosine triphosphate	R̸	u=	R̸, s	R̸	R̸	u=[5]	R̸	R̸	R̸
5	Adenylic acid	R̸, s	u=, s	r, u<[3]	R̸	R̸	u=[5]	R̸	R̸, u	R̸
6	Guanine	R̸	r	r[7]	s	R̸	u=[5,8], s	R̸	r, rm, s	R̸
7	Guanosine	R̸	u=, s	r?, u=, u<[9], i	R̸	R̸	u=[5]	R̸	R̸, u	R̸
8	Guanylic acid	R̸	u=, s	u=, s	R̸	R̸	u=[5]	R̸	R̸, u	R̸
9	Hypoxanthine	R̸	u	u=, u<[3]	s	R̸	u=[5], s	R̸	rm, u, s	R̸
10	Xanthine	R̸	s	r?[10], u̸	R̸	R̸	u=[5]	R̸	R̸, u	R̸
11	Others	...	....	s[11]	......	...	....	...	u	R̸
12	Pyrimidine compounds	R̸, s	r	r, s	r	r	r, s, u	r, s	r, rm, s	R̸
13	Cytidine	R̸	R̸	u=, i	R̸	R̸	u=[12]	R̸	R̸, rm, s	R̸
14	Cytidylic acid	R̸	R̸	u=, s	R̸	R̸	u=[12]	R̸	R̸, rm, s[13]	R̸
15	Cytosine	R̸	R̸	r?, u̸, i	R̸	R̸	u=[8]	R̸	rm, u	R̸
16	Orotic acid	R̸, s	R̸	R̸, u̸	R̸	R̸	r[14], s	R̸	rm, s[13], u	R̸
17	Pyrimidine	R̸, u̸	R̸	r, u[15]	r, u[15]	r[15]	r, u[15]	r, s[15]	r, rm, u[15]	R̸
18	Thymine	R̸, s	r, s	r?, u<[16]	R̸, u<[4]	R̸	u=[17], u<[18]	R̸	R̸, u	R̸
19	Thymidine	R̸, s	u=	u<[18]	R̸	R̸	u<[18]	R̸	R̸	R̸
20	Uracil	R̸	r	r, u=[19]	r?	R̸	u=[12], s	R̸	rm, s[13]	R̸
21	Uridine	R̸	R̸	u=	R̸	R̸	u=[12], s	R̸	R̸, rm, s	R̸
22	Uridylic acid	R̸	R̸	u=	R̸	R̸	u=[12], s	R̸	R̸, rm, s[13]	R̸
	Reference	1,8,12, 15,16	11,18, 19,21	6,13,22-24, 27-29,42	6,13,14, 21,28-30	2,4,5,21,26, 30,33,36,40	8,10,17, 21,31,35, 41,44,45	8,10,17,21, 31,35,44-46	7,8,10,17, 21,31,34,35, 37,44,45	3,9,20,25, 32,38,39, 43

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /3/ Spares, but cannot replace, guanine, guanosine, and guanylic acid in *Tetrahymena*. /4/ Spares and, when given with amino acids, substitutes for *p*-aminobenzoic and pteroylglutamic acids in *Euglena gracilis*. /5/ Items 2-10 are variously interchangeable for different bacteria, but at least one must be present (e.g., *Streptococcus pyogenes* requires at least one of adenine, adenosine, adenylic acid, guanine, guanosine, guanylic acid, xanthine); requirement is relieved by CO_2 in high concentration. *S. lactis* requires adenine, guanine, hypoxanthine, or xanthine. *Bacillus megaterium* requires adenosine for spore germination. /6/ Required by *Saccharomyces octosporus* on certain media. /7/ Required by *Tetrahymena*, but is replaceable by guanosine or guanylic acid. /8/ *Lactobacillus plantarum* and *Leuconostoc mesenteroides* require cytosine or guanine (interchangeable). /9/ Spares pteroylglutamic acid in *Herpetomonas culicidarum*. /10/ In vitro studies indicate possibility that *Plasmodium* requires xanthine (and also cytosine, pyrimidine, uracil, adenine, and guanosine). /11/ Methyl purines (theobromine, theophylline, caffeine) stimulate some ciliates and Suctoria. /12/ At least one required, but interchangeable, for several species (e.g., *Clostridium tetani, Haemophilus parainfluenzae*). /13/ Stimulates mutants of *Neurospora*. /14/ Required by *Lactobacillus bulgaricus* 09. /15/ Pyrimidine moiety of thiamine. /16/ Spares pteroylglutamic acid in *Tetrahymena*. /17/ *Clostridium tetani* requires either adenine or hypoxanthine (interchangeable). /18/ Spares pteroylglutamic acid in *Streptococcus lactis*; thymine + thymidine replaces pteroylglutamic acid in *S. lactis*. /19/ Replaces, or is interchangeable with, cytidine, cytidylic acid, uridine, or uridylic acid, in *Tetrahymena*.

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47. NUTRIENTS: VITAMINS AND RELATED COMPOUNDS

It is probable that many vitamins and related compounds are indispensable participants in the metabolic activities of all living substances, and are in this sense universally "required." Data, however, have been limited to the presently known requirement, or non-requirement, for compounds obtained from the external environment or in the diet, and do not include metabolically essential compounds provided to an organism by associated microorganisms (e.g., by the intestinal flora of mammals). *Abbreviations:* Capital letters indicate data are pertinent to all organisms studied; lower case letters and symbols indicate data apply to one or more species, or strains, but not to all forms studied. R and r = required; R̸ = not required; rm = required by one or more mutants; u = utilized; u= = utilized as effectively as a related vitamin or compound; u> = utilized more effectively than a related vitamin or compound; u< = utilized less effectively than a related vitamin; u̸ = not utilized in place of the related vitamin; s = stimulates growth or other processes; i = inhibits growth or other processes.

	Compound	Vertebrata	Invertebrata		Phytoflagellata (green)[2]	Algae	Bacteriophyta	Fungi		Spermatophyta
			Insecta	Protozoa[1]				Saccharomycetaceae	Other	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Vitamins									
1	Vitamin A	R	R̸	r?	R̸	R̸	R̸	R̸	R̸	R̸, s
2	*p*-Aminobenzoic acid	R̸, s	R̸	r	R̸	R̸	r	r	r, rm, s	R̸

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina.

continued

47. NUTRIENTS: VITAMINS AND RELATED COMPOUNDS

	Compound	Vertebrata	Invertebrata		Phyto-flagellata (green)[2]	Algae	Bacterio-phyta	Fungi		Sperma-tophyta
			Insecta	Protozoa[1]				Saccharo-mycetaceae	Other	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Vitamins									
3	Ascorbic acid	r	r	r, s	Ɍ	r?, s	Ɍ, s	Ɍ, s	Ɍ, s	Ɍ, s
4	Biotin	r	r	r, s	Ɍ	r	r	r, s	r, rm, s	Ɍ
5	Choline group[3]	r	r	Ɍ	Ɍ	Ɍ	r	Ɍ	r, rm	Ɍ, s
6	Cobalamin[4]	r	r?, s	r	r	r	r[5]	Ɍ	Ɍ	Ɍ, s
7	Vitamin D[6]	R	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ, s	Ɍ
8	Vitamin E	r	Ɍ, s	r[7]	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ
9	Inositol[8]	r?	r	Ɍ	Ɍ	Ɍ	r?, s	r, s	r, rm, s	Ɍ, s
10	Vitamin K	r	Ɍ	Ɍ	Ɍ	Ɍ	r	Ɍ	Ɍ	Ɍ
11	Nicotinic acid	r	r	r	Ɍ	Ɍ	r, s	r	r, rm, s	Ɍ, s?
12	Nicotinamide	u=	u=	u=	Ɍ	Ɍ	r, u=, s	u=	r, rm, s	Ɍ, s?
13	Pantothenic acid	R	r	r	Ɍ	r	r, s	r	r, rm, s	Ɍ, s
14	Pteroylglutamic acid[9]	R	r	r	Ɍ	Ɍ	r[10]	Ɍ	Ɍ, s	Ɍ
15	Pyridoxal[11]	u=	u=	u=	Ɍ	Ɍ	r, u>	u=, s	u=	Ɍ
16	Pyridoxamine[11]	u=	u=	u=	Ɍ	Ɍ	r, u>	u=, s	u=	Ɍ
17	Pyridoxine	R	r	r	Ɍ	Ɍ, s	r, s	r, s	r, rm, s	Ɍ, s
18	Riboflavin	R	r	r	Ɍ	Ɍ	r, s	Ɍ	r, rm	Ɍ
19	Thiamine	R	r	r	r	r	r, s	r, i[12]	r, rm, s, i[13]	Ɍ, s
	Compounds Chemically Related to Vitamins									
20	β-Alanine	Ɍ, s	Ɍ	Ɍ, u̸	Ɍ	Ɍ	Ɍ, u=	Ɍ, u=	rm, u=	Ɍ
21	Biocytin	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	u	Ɍ	Ɍ, u=	Ɍ
22	β-Carotene[14]	Ɍ, u<	r	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ
23	Coenzyme A	Ɍ, u<	Ɍ, u=	Ɍ	Ɍ	Ɍ	r, u>	Ɍ, s	Ɍ	Ɍ
24	5,6-Dimethylbenzimi-dazole	Ɍ, u<	Ɍ	Ɍ	Ɍ, u<	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ
25	Desthiobiotin	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ, u>	Ɍ	Ɍ, u=	Ɍ
26	Diphosphopyridine nu-cleotide	Ɍ, u=?	Ɍ, u=?	Ɍ	Ɍ	Ɍ	r, u=	Ɍ, u=	r, u>, s	Ɍ
27	Diphosphothiamine	Ɍ, u=	Ɍ, u=	Ɍ, u=	Ɍ, u=	Ɍ	r, u>	Ɍ, u=	Ɍ, u<	Ɍ
28	Folic acid conjugates[15]	Ɍ, u=	Ɍ, u=	Ɍ, u=	Ɍ	Ɍ	Ɍ, u=	Ɍ	Ɍ	Ɍ
29	Folinic acid[16]	Ɍ, u<	Ɍ, u=	Ɍ, u=	Ɍ	Ɍ	r	Ɍ	Ɍ	Ɍ
30	Hesperidin[17]	Ɍ, s	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ, s
31	*o*-Heterobiotin	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ, u<, u̸	Ɍ	Ɍ	Ɍ
32	LBF[18]	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	r, u>	Ɍ	Ɍ	Ɍ
33	Lipothiamide	Ɍ, u=	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ
34	Lyxoflavin	Ɍ, s, u<	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ, u<[19]	Ɍ	Ɍ	Ɍ
35	Oxybiotin	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ, u<	Ɍ	Ɍ, s	Ɍ
36	Pantoic acid	Ɍ, u̸	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ, u	Ɍ, u	Ɍ	Ɍ
37	Pantothenic acid con-jugate	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	r?, u>	Ɍ	Ɍ	Ɍ
38	Pimelic acid	Ɍ, u̸	Ɍ	Ɍ, u<	Ɍ	Ɍ	Ɍ, u=?	Ɍ	Ɍ, s	Ɍ
39	Pseudovitamin B_{12}	Ɍ, u̸	Ɍ	Ɍ	Ɍ, u=	Ɍ	Ɍ, u=	Ɍ	Ɍ	Ɍ
40	Pteroic acid	Ɍ, u̸	Ɍ	Ɍ, u=, u̸	Ɍ	Ɍ	Ɍ, u<	Ɍ	Ɍ	Ɍ
41	Pyridoxal-PO_4	Ɍ, u=	Ɍ, u=	Ɍ, u=	Ɍ	Ɍ	r, u>	Ɍ, u	Ɍ, u=	Ɍ
42	Pyridoxamine-PO_4	Ɍ, u=	Ɍ, u=	Ɍ, u=	Ɍ	Ɍ	r, u>	Ɍ, u	Ɍ, u=	Ɍ
43	Pyrimidine	Ɍ, u̸	Ɍ	r, u[20,21]	r, u[20,21]	r[20,21]	r, u[20,21]	r, s[20,21]	r, rm, u[20,21]	Ɍ
44	Rhizopterin	Ɍ, u̸	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ, u=	Ɍ	Ɍ	Ɍ
45	α-Ribazole	Ɍ, s	Ɍ	Ɍ	Ɍ, u<	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /3/ Includes choline, betaine and other methyl donors. /4/ Generic term; includes cyanocobalamin, hydroxocobalamin, vitamins B_{12}, B_{12a}, and B_{12b}. /5/ For some species or strains, thymine desoxyriboside, hypoxanthine, adenine, or guanine may substitute in certain media. /6/ D_2 active for mammals only; D_3 active for all and required by chicken. /7/ Required by a variant of *Trichomonas gallinae*. /8/ Of doubtful status as a vitamin. /9/ Folic acid, folacin. /10/ For some species or strains, pteroic acid, or thymine + thymidine, will substitute. /11/ Member of the pyridoxine group (vitamin B_6). /12/ Inhibits growth of *Saccharomyces cerevisiae* strains. /13/ Inhibits growth of *Rhizopus nigricans*. /14/ And other carotenoid precursors of vitamin A. /15/ Di-, tri- and hepta-glutamates of pteroylglutamic acid. /16/ The citrovorum factor; required by *Leuconostoc citrovorum*. /17/ Hesperidin, rutin and citrin = vitamin P series. /18/ *Lactobacillus bulgaricus* factor = pantetheine (thiol form), and pantethine (disulfide form). /19/ Replaces riboflavin in *Lactobacillus lactis*. /20/ Thiamine or pyrimidine moiety (thiazole moiety is synthesized). /21/ Thiamine or pyrimidine + thiamine moieties (pyrimidine and thiazole moieties combine to give thiamine).

continued

47. NUTRIENTS: VITAMINS AND RELATED COMPOUNDS

	Compound	Vertebrata	Invertebrata		Phyto-flagellata (green)[2]	Algae	Bacteriophyta	Fungi		Spermatophyta
			Insecta	Protozoa[1]				Saccharomycetaceae	Other	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Compounds Chemically Related to Vitamins									
46	Rutin[17]	R̶, s	R̶	R̶	R̶	R̶	R̶	R̶	R̶, u[22]	R̶
47	Thiazole	R̶	R̶	r, u[21,23]	r, u[21,23]	r[21,23]	r, u[21,23]	r, s[21,23]	r, rm, u[21,23]	R̶
48	Triphosphopyridine nucleotide	R̶, u=	R̶	R̶	R̶	R̶	R̶, u=	R̶, u=	r, u>, s	R̶
49	Xanthopterin	r?[24], u>[24], s	R̶	R̶	R̶	R̶	R̶, u<	R̶	R̶	R̶
	Reference	1-6,12-16, 29,32-34, 38,40-44, 52	6,9,19, 23,24, 40,48, 50,52	6,8,11,20, 21,25,28, 30,40,52	6,8,20, 21,28,30, 31,48	6,7, 27,30, 31,46	35,36,40, 45,47,49, 52	6,17,22,26, 36,47,49,51	6,10,17,18, 22,26,36, 37,39,45,49	4,6,45

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /17/ Hesperidin, rutin and citrin = vitamin P series. /21/ Thiamine or pyrimidine + thiamine moieties (pyrimidine and thiazole moieties combine to give thiamine). /22/ Utilized by *Aspergillus flavus*, *Polyporus versicolor*. /23/ Thiamine or thiazole moiety (pyrimidine moiety is synthesized). /24/ More active than pteroylglutamic (folic) acid in relieving anemia of Chinook salmon.

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47. NUTRIENTS: VITAMINS AND RELATED COMPOUNDS

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48. NUTRIENTS: MISCELLANEOUS GROWTH FACTORS

Many of the compounds listed are utilized by some organisms only for their carbon, nitrogen, and/or hydrogen content (e.g., CO_2, glutamine, and asparagine). *Abbreviations:* Capital letters indicate data are pertinent to all organisms studied; lower case letters and symbols indicate data apply to one or more species, or strains, but not to all forms studied. R and r = required; R̸ = not required; rm = required by one or more mutants; ⊨ = replaces effectively, or is utilized interchangeably with, one or more substances, but one of the interchangeable substances must be present; s = stimulates growth or other processes; i = inhibits growth or other processes.

	Nutrient	Vertebrata	Invertebrata		Phytoflagellata (green)[2]	Algae	Bacteriophyta	Fungi		Spermatophyta
			Insecta	Protozoa[1]				Saccharomycetaceae	Other	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
1	Adenylthiomethylpentose[3]	R̸, s	R̸	R̸	R̸	R̸	R̸	R̸	R̸	R̸
2	Anthranilic acid[4]	R̸, s	R̸	R̸	R̸	R̸	⊨[5]	R̸	r, rm[5]	R̸
3	Antibiotics[6]	R̸, s	R̸	R̸, s	R̸	R̸	r[7]	R̸	R̸, s	R̸, s
4	Asparagine	R̸	R̸	R̸	R̸	R̸	r[8]	R̸, s, i	R̸	R̸
5	Bifidus factor	R̸	R̸	R̸	R̸	R̸	r	R̸	R̸	R̸
6	Carbon dioxide	R̸	R̸	r[9]	R[10], s	R	r[11], s	......	r[11], s, i	R
7	Carnitine[12]	R̸	r[13]	R̸	R̸	R̸	R̸	R̸	R̸	R̸
8	Coprogen[14]	R̸	R̸	R̸	R̸	R̸	R̸	R̸	r	R̸
9	*N*-D-Glucosylglycine ester	R̸	R̸	R̸	R̸	R̸	r	R̸	R̸	R̸
10	Glutamine	R̸	R̸	R̸	R̸	R̸	r[8], s	s, i	R̸, s, i	R̸
11	Glutathione	R̸	s[15]	R̸	R̸	R̸	r[16]	R̸	R̸	R̸
12	Guanidine	R̸	R̸	r ?[17]	R̸	R̸	R̸	......	R̸	R̸
13	Indole-3-acetic acid[18]	R̸, s?	R̸	R̸[19], i	R̸, s[19]	R̸, s	R̸, s	R̸	r?, s	R̸, s
14	Hematin[20]	R̸	r	r	R̸	R̸	r	R̸	r	R̸
15	*p*-Hydroxybenzoic acid	R̸	R̸	R̸	R̸	R̸	rm	R̸	rm	R̸
16	Krebs cycle intermediates[21]	R̸	R̸	R̸, s[22]	r[22], s	R̸	r	R̸	r	R̸

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /3/ "Vitamin L_2," a purine nucleoside. /4/ "Vitamin L_1," precursor of nicotinic acid. /5/ Substitutes for tryptophan and/or indole. /6/ Aureomycin, penicillin, streptomycin, bacitracin, neomycin, and other anti-infectious substances (e.g., arsenicals and sulfonamides which in small amounts may stimulate growth). /7/ Required by "dependent" mutants. /8/ Required as growth factor and not replaceable by aspartic or glutamic acids. /9/ Required by some colorless Phytoflagellata. /10/ Required although another carbon source is available, particularly in darkness. Functions in metabolism of C_3 and C_4 compounds. /11/ Required in higher-than-atmospheric concentrations by some species. /12/ α-Hydroxy-γ-aminobutyric acid. /13/ Required by *Tenebrio molitor;* interchangeable with γ-amino-β-hydroxybutyric acid. /14/ Fe-containing molecule of unknown structure; not a heme compound. /15/ Favors larval growth of *Drosophila* and *Aedes aegypti*. /16/ Required by *Neisseria gonorrhoeae*. /17/ Possibly required in vitro by *Plasmodium;* not required by *Tetrahymena*. /18/ And related auxins (plant hormones). /19/ Ineffective for *Astasia* (colorless counterpart of *Euglena*); stimulates growth of *Euglena gracilis* (green Phytoflagellata). /20/ Also hemin, protohemin, protoporphyrin, and several other porphyrins. /21/ Acetate, citrate, fumarate, α-ketoglutarate, oxalacetate, succinate, *cis*-aconitate, isocitrate, malate, and oxalosuccinate. /22/ Several intermediates are utilized for growth by the "acetate" flagellates; acetate is utilized by most species. There is wide variation among species with respect to utilization or availability of individual Krebs intermediates and related compounds, such as pyruvate.

continued

48. NUTRIENTS: MISCELLANEOUS GROWTH FACTORS

	Nutrient	Vertebrata	Invertebrata		Phytoflagellata (green)[2]	Algae	Bacteriophyta	Fungi		Spermatophyta
			Insecta	Protozoa[1]				Saccharomycetaceae	Other	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
17	Mucin	℞, s	℞	℞	℞	℞	r[23]	℞	℞	℞
18	Mycobactin[24]	℞	℞	℞	℞	℞	r[25]	℞	℞	℞
19	Putrescine	℞	℞	℞	℞	℞	r, uF[26]	℞	rm	℞
20	Quinic acid[27]	℞	uF[28]	℞	℞	℞	rm	℞	rm	℞
21	Shikimic acid[27]	℞	uF[28]	℞	℞	℞	rm	℞	rm	℞
22	Spermidine[29]	℞	℞	℞	℞	℞	r, uF[26]	℞	℞	℞
23	Strepogenin[30]	℞, s?	℞	℞	℞	℞	r, rm, s	℞	℞, s?	℞
24	Thioctic acid[31]	℞	℞	r[32]	℞	℞	r	℞	℞	℞
25	Unidentified factors[33]	r	r	r	.....	....	r	......	r	....
	Reference	5,45	15,16, 22,39	2,6,8,11, 18,24,25, 31,33	6,11,18, 23,31,33	3,12,14, 29,31, 34,38,41	10,21,27, 35-37, 42-44	1,13,19,20, 28,43,44	1,7,9, 13,17, 20,30	4,26,32, 40

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /23/ Required by *Corynebacterium diphtheriae*. /24/ $C_{47}H_{75}ON_5$. /25/ Required by *Mycobacterium paratuberculosis*. /26/ Interchangeable with spermidine in some species. /27/ Probable precursors of aromatic amino acids. /28/ Spares or replaces phenylalanine or tyrosine in *Blattella germanica*. /29/ Also agmatine and spermine. /30/ Also D-alanyl-histidine, amino-*n*-butyryl-L-histidine, carnosine, and various tyrosine peptides. /31/ Protogen or α-lipoic acid. Exists in tissues as lipothiamide which catalyzes the oxidation of pyruvate and α-ketoglutarate. /32/ Required by *Tetrahymena geleii* (8 strains), and *T. vorax* (2 strains); spared but not replaced by acetate; required (?) by *Peranema trichophorum*. /33/ Tissue extracts and unknown substances or complexes in living tissue or protoplasm.

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49. NUTRIENTS: CARBON, NITROGEN, AND SULFUR

Part I. CARBON SOURCES

Abbreviations: Capital letters indicate data are pertinent to all organisms studied; lower case letters and symbols indicate data apply to one or more species, or strains, but not to all forms studied. R and r = required; Ɍ = not required; U and u = utilized; Ʉ = not utilized; * = may serve as sole or partial carbon source; ** = simplest carbon source.

	Carbon Source	Vertebrata	Invertebrata: Insecta	Invertebrata: Protozoa[1]	Phytoflagellata (green)[2]	Algae	Bacteriophyta	Fungi: Saccharomycetaceae	Fungi: Other	Spermatophyta
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Inorganic Carbon									
1	Carbon, amorphous, C	Ʉ	Ʉ	Ʉ	Ʉ	Ʉ	u**?	Ʉ	u?	Ɍ
2	Carbon monoxide, CO	Ʉ	Ʉ	Ʉ	Ʉ	Ʉ?	u[3]	Ʉ	Ʉ	Ʉ
3	Carbon dioxide, CO_2	U	U?	r, u*[4]	r, U**	R, U**	r, u**	...	r, U	R, U**
4	Bicarbonates, $-HCO_3^-$	U	U?	r, u*[4]	r, U**	U**?	r, u**	...	U	R, U**
5	Cyanogens, $-CN^-$	....	....	.....	......	......	u	...	u	?
	Organic Carbon									
6	Alkanes, alkenes	Ʉ	Ʉ	Ʉ	Ʉ	Ʉ	u[5]	Ʉ	u	Ʉ
7	Alcohols	U	u	u	Ɍ, u	Ɍ, u	u	u	u*	u
8	Aldehydes	Ɍ, u	Ɍ	Ɍ	Ɍ	Ɍ	u	u	u	Ɍ
9	Ketones	Ɍ, u	Ɍ	u	Ɍ	Ɍ	u	...	Ʉ	Ɍ
10	Acids	r, U	r, U	u	Ɍ, u	Ɍ, u	u	u	u*	Ɍ
11	Carbohydrates	U	r, U	r, u[6]	Ɍ, u	Ɍ, u	U*	U*	U*	U[7]
12	Glycosides	Ɍ, u	Ɍ	Ɍ	Ɍ, u	u	u	u	u	Ɍ
13	Fats	U	r, U[8]	u	Ɍ, Ʉ	Ɍ, Ʉ	u	u	u	Ɍ, Ʉ
14	Waxes	u	u	Ɍ, Ʉ	Ɍ, Ʉ	Ɍ, Ʉ	u	...	u*	Ɍ, Ʉ
15	Amino acids, peptides, proteins	R, U	u	u	Ɍ, u	Ɍ, u	u	u	u*	Ɍ, u
	Reference	13,17, 19,25	5,9,26	2,6,12,16	2,6,12, 16,21	10,21	1,18,22, 24	1,4,7,8,11, 18,22,24	3,4,7, 11	14,15,20, 23

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /3/ Utilized by *Carboxydomonas oligocarbophila* and *Sarcina barkeri*. /4/ Utilized by *Tetrahymena geleii* (condensation with pyruvate, oxalacetate, succinate). Required by *Chilomonas paramecium* and *Astasia longa*, but not on acetate medium. Required by *Polytomella caeca* on media containing casein hydrolysate, and also on acetate medium. /5/ Utilized by *Sarcina methanica:* ethane, propane, butane, hexane, propylene, butylene, and paraffin oils. Utilized by other species: gasoline, kerosene, mineral oils, paraffin wax, etc. /6/ Carbohydrate carbon source not required by *Tetrahymena geleii* except when utilizing NH_4^+ in a medium low in amino acids. /7/ Utilized by isolated tissues (e.g., roots, callus and tumor tissues, green plants in aseptic culture). /8/ Insects do not require dietary fats other than specific lipids as growth substances and vitamins.

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49. NUTRIENTS: CARBON, NITROGEN, AND SULFUR

Part I. CARBON SOURCES

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Part II. NITROGEN SOURCES

Nitrogen is a universal requirement of living organisms. Although some utilize it as molecular nitrogen, most organisms require it in the form of compounds. *Abbreviations:* Capital letters indicate data are pertinent to all organisms studied; lower case letters and symbols indicate data apply to one or more species, or strains, but not to all forms studied. R and r = required; R̸ = not required; rm = required by one or more mutants; U and u = utilized; U̸ and u̸ = not utilized; s = stimulates growth or other processes; * = serves as adequate or partial nitrogen source; ** = simplest adequate nitrogen source.

	Nitrogen Source	Vertebrata	Invertebrata		Phytoflagellata (green)[2]	Algae	Bacteriophyta	Fungi		Spermatophyta
			Insecta	Protozoa[1]				Saccharomycetaceae	Other	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Inorganic Nitrogen									
1	Nitrogen, molecular, N_2	U̸	U̸	U̸	U̸	R̸, u**[3]	u**[4]	R̸	R̸, u?[5]	u[6]
2	Ammonia, NH_3; ammonium, $-NH_4^+$	R̸, u[7]	R̸, u?	r, u**	R̸, U**	R̸, U**[8]	R̸, u*[9]	R̸, u**	rm, u**[10]	R̸, U**
3	Hyponitrite, $-HN_2O_2^-$ or $-N_2O_2^=$	R̸	R̸	R̸	R̸	R̸	R̸, u[11]	......	R̸, u̸[12]	R̸, u̸[13]
4	Nitrite, $-NO_2^-$	R̸	R̸	R̸	R̸	R̸, u*[14]	R̸, u*	R̸, u*	rm, u**[15]	R̸, u*[16]
5	Nitrate, $-NO_3^-$	R̸	R̸	R̸, u	R̸, u*[17]	R̸, U*[17]	R̸, u*[18]	R̸, u*[19]	rm, u**[20]	R̸, U*

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /3/ Utilized in nitrogen fixation by blue-green algae (Nostocaceae). Not utilized if hydrogen or carbon monoxide are present. /4/ Utilized by nitrogen-fixing bacteria. /5/ Evidence is conflicting for nitrogen fixation. /6/ Utilized via symbiotic bacteria, as in root nodules of legumes. /7/ Ruminants, and possibly other vertebrates, utilize dietary NH_4^+. NH_4^+ originating as a metabolic intermediate is utilized in amino acid synthesis. /8/ Utilized by *Chlorella* in preference to NO_3^-. /9/ Many bacteria require specific amino acids from the environment, but as a class they utilize NH_4^+ for synthesis of other amino acids. /10/ Utilized by *Phycomyces blakesleeanus* (Mucorales). Probably utilized by all fungi. /11/ Utilized by *Clostridium pasteurianum* but not for growth; not utilized for denitrification by *Pseudomonas stutzeri*. /12/ Not utilized by *Aspergillus niger*. /13/ Not utilized by *Nicotiana*. /14/ Utilized poorly by *Chlorella pyrenoidosa*. /15/ Utilized as sole nitrogen source by many fungi. /16/ Toxic to many plants; poorly utilized by *Nicotiana*. /17/ Utilized in light. /18/ Not utilized by purple photosynthetic bacteria. /19/ Poorly utilized by most yeasts. /20/ Acts as sole hydrogen acceptor in anaerobic metabolism of *Aspergillus niger*. Required by some species when manitol is the carbon source. Some species require NO_3^-.

continued

49. NUTRIENTS: CARBON, NITROGEN, AND SULFUR

Part II. NITROGEN SOURCES

	Nitrogen Source	Vertebrata	Invertebrata		Phytoflagellata (green)[2]	Algae	Bacteriophyta	Fungi		Spermatophyta
			Insecta	Protozoa[1]				Saccharomycetaceae	Other	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Inorganic Nitrogen									
6	Nitrohydroxamate, $-HN_2O_3^-$	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ, u*[21]	Ɍ, u*[22]
7	Cyanide, $-CN^-$	Ʉ[23]	Ʉ[23]	Ʉ[23]	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ, u*[24]	Ʉ
8	Thiocyanate, $-CNS^-$	Ʉ	Ʉ	Ʉ	Ɍ	Ɍ	Ɍ, u*	Ɍ, u	Ɍ, u?	Ʉ
9	Cyanamide, $-NHCM^-$	Ʉ	Ʉ	Ʉ	Ɍ	Ɍ	Ɍ, u*[25]	Ɍ	u*[25]	Ʉ
	Organic Nitrogen									
10	Oximino compounds[26], $RONH_2$	Ɍ	Ɍ	Ɍ	Ɍ	Ʉ[27]	Ɍ, u*[28]	Ɍ, u?	Ɍ, u*	Ɍ, U[29]
11	Amines[30], RNH_2	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ, u*[31]	Ɍ, u*	Ɍ, u*	Ɍ, u*	Ɍ
12	Acid imides, $(RCO)_2NH$	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ, u*	Ɍ	Ɍ	Ɍ
13	Acid amides, $RCONH_2$	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ, u*	Ɍ, u*	r, u*	Ɍ, u*[32]	Ɍ, u*[33]
14	Urea, $(NH_2)_2CO$	Ɍ, u[34]	Ɍ	Ɍ, u*[35]	Ɍ, u*	Ɍ, u*	Ɍ, u*	Ɍ, u*	Ɍ, u*	Ɍ, U*
15	Amino acids, $RCH(NH_2)COOH$	R, U**[7]	R, U**	r, u*	r, u*	Ɍ, u*[36]	r[9], U*, s	r, U*	r, rm, U*	Ɍ, u*
16	Peptides, polypeptides[37]	Ɍ, U*	Ɍ	r, u*	Ɍ, u*	Ɍ, u*	r, u*, s	Ɍ, u*	Ɍ, u*	Ɍ, u*
17	Proteins (per se)	Ɍ[38], U*, s	Ɍ, U*	r, u*	Ɍ	Ɍ	Ɍ, u*	Ɍ	Ɍ, u*	Ɍ
18	Imidazole compounds	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ, u*	Ɍ, u*	Ɍ, u*	Ɍ
19	Pyridine compounds	r	r	r	Ɍ	Ɍ	r, u*	r	Ɍ	Ɍ
20	Pyrimidine compounds	R	r	r, u*	r	r	Ɍ, u*, s	Ɍ, u*	Ɍ, u*, s	Ɍ
21	Purine compounds	Ɍ	Ɍ	r, u*	Ɍ	Ɍ	Ɍ, u*, s	Ɍ, u	rm, u*, s	Ɍ, u
22	Indole compounds	Ɍ	Ɍ	Ɍ	Ɍ, s	Ɍ, s	Ɍ, u*, s	Ɍ	rm, u*	Ɍ, s
	Reference	1,3,13, 17,18, 50	12,20, 48	8,14-16, 23,26,27, 32,42	8,14,26, 27,32,34, 40,42	4,9,11, 21,22,25, 29,33,34, 37,38,44, 45	24,39,46, 49	2,5	7,10,19, 28,41	6,30,31, 35,36,43, 47,49

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /7/ Ruminants, and possibly other vertebrates, utilize dietary NH_4^+. NH_4^+ originating as a metabolic intermediate is utilized in amino acid synthesis. /9/ Many bacteria require specific amino acids from the environment, but as a class they utilize NH_4^+ for synthesis of other amino acids. /21/ Good nitrogen source for *Aspergillus niger*. /22/ Good nitrogen source for *Nicotiana*. /23/ Toxic. /24/ Utilized by *Aspergillus niger* when nitrogen-starved. /25/ Many species utilize cyanamide and derivatives. /26/ Including hydroxylamine. /27/ Hydroxylamine is toxic. /28/ *Clostridium perfringens* utilizes hydroxylamine; *Nitrosomonas* utilizes a nontoxic concentration. /29/ Hydroxylamine is poor nitrogen source. /30/ Alkylamines, as methylamine (CH_3NH_2), and arylamines, as benzylamine ($C_6H_5CH_2NH_2$). /31/ All organisms studied utilize glucosamine. /32/ *Aspergillus* utilizes formamide and other acid amides; utilizes both amino and amide nitrogen of asparagine. /33/ Some species utilize acetamide. /34/ Utilized by ruminants via rumen microflora. /35/ Utilized by *Astasia longa*. /36/ L-Arginine, glutamine, cysteine and L-asparagine support more rapid growth of *Chlorella* than does NH_4^+. /37/ Including peptones, synthetic di- and tri-peptides, strepogenin, and glutathione. /38/ Proteins, per se, are listed as "not required" for vertebrates, since only certain amino acids are required.

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Part III. SULFUR SOURCES

Sulfur occurs in several amino acids: cysteine, cystine, and methionine. Methionine is required by all animal forms studied and may be essential in the protein structure of all living organisms. Sulfur occurs also in chondroitin sulfuric acid, a component of vertebrate connective tissue, and in sulfolipids found in the white matter of the brain and in other tissues. *Abbreviations:* Capital letters indicate data are pertinent to all organisms studied; lower case letters and symbols indicate data apply to one or more species, or strains, but not to all forms studied. R and r = required; R̸ = not required; rm = required by one or more mutants; U and u = utilized; U̸ = not utilized.

	Sulfur Source	Vertebrata	Invertebrata		Phytoflagellata (green)[2]	Algae	Bacteriophyta	Fungi		Spermatophyta
			Insecta	Protozoa[1]				Saccharomycetaceae	Other	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Inorganic Sulfur									
1	Sulfur[3] (elemental), S	R̸, u[4]	R̸	R̸	R̸	R̸, U̸	r[5]	u	u[6]	R̸, U̸
2	Sulfhydryl, $-SH^-$	R̸	R̸	R̸	R̸	R̸	...	...	u	R̸

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /3/ The substance alone, not in combination with other elements. /4/ In ruminants, bacteria build the element into amino acids (methionine, cystine). /5/ Utilized by *Thiobacillus thiooxidans*, *Desulfovibrio desulfuricans*, and *D. aestuarii* (Thiorhodaceae). /6/ Utilized by *Fusarium lini*.

continued

49. NUTRIENTS: CARBON, NITROGEN, AND SULFUR

Part III. SULFUR SOURCES

	Sulfur Source	Vertebrata	Invertebrata: Insecta	Invertebrata: Protozoa[1]	Phytoflagellata (green)[2]	Algae	Bacteriophyta	Fungi: Saccharomycetaceae	Fungi: Other	Spermatophyta
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Inorganic Sulfur									
3	Sulfide, $-S^{=}$	Ɍ, Ʉ	Ɍ	Ɍ	Ɍ	Ɍ, u[7]	u[8]	...	u[9]	Ɍ
4	Bisulfite, $-HSO_3^-$	Ɍ, Ʉ	Ɍ	Ɍ	Ɍ	Ɍ	...	...	u[10]	Ɍ
5	Sulfite, $-SO_3^{=}$	Ɍ, Ʉ	Ɍ	Ɍ	Ɍ	Ɍ	u[11]	...	u[10]	Ɍ, u
6	Sulfate, $-SO_4^{=}$	Ɍ, u[12]	Ɍ	r	U	U	r	u	u[10]	U
7	Thiosulfate, $-S_2O_3^{=}$	Ɍ, Ʉ	Ɍ	Ɍ	Ɍ	Ɍ	u[13]	...	rm, u	Ɍ, u
8	$-S_2O_8^{=}$[14]	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	...	...	u?	Ɍ
9	Tetrathionate, $-S_4O_6^{=}$	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	u	...	.....	Ɍ
10	Sulfoxylate, $-SOOH^-$	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	u	...	u[15]	Ɍ
11	-SO as sulfur hydrate, H_2SO	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	u	...	.....	Ɍ
12	Thiocyanate, $-SCN^-$	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	u[16]	...	u	Ɍ
13	Persulfate	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	...	...	u[10]	Ɍ
	Organic Sulfur[17]									
14	Cystathionine	u	u	Ɍ, u	Ɍ	Ɍ	u	...	u	Ɍ
15	Cysteine	U	u[18]	u	Ɍ, u	Ɍ, u[19]	r	u	u[9]	Ɍ, u
16	Cystine	U	u	u	Ɍ, u	Ɍ	r	u	u[9]	Ɍ, u
17	Homocysteine	u	u	Ɍ, u	Ɍ	Ɍ	u	...	U	Ɍ
18	Homocystine	u	u	Ɍ, u	Ɍ	Ɍ	u	...	U	Ɍ
19	Methionine	R	r[20]	r	r	Ɍ, Ʉ	r	u	U	Ɍ, u
20	Peptones	Ɍ, U	u	r	u	Ɍ, u	u	u	U	Ɍ, u
21	Biotin[21]	R?, U	r	r?	r	Ɍ	u	u	u	Ɍ
22	Coenzyme A	Ɍ, U	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ
23	Glutathione ("G-SH")[22]	Ɍ, U	u	Ɍ, u	u	Ɍ	r	u	u	Ɍ
24	Thiamine[23]	R	r	r	r	u	r	r	Ʉ	Ɍ
25	Thiazole[23]	Ɍ	Ɍ	r[24], u	r[24]	r	r[24]	r[24]	u?[25]	Ɍ
26	Thioctic acid[26]	Ɍ	Ɍ	r[27]	Ɍ	Ɍ	r[28]	Ɍ	Ɍ	Ɍ
	Miscellaneous									
27	Alkylsulfides, R-S-S-R	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	...	...	u[29]	Ɍ
28	Alkylsulfinates, $R-SO_4-R$	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	...	...	u	Ɍ
29	Alkylsulfonates, $R-SO_3-R$	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	...	...	u	Ɍ
30	Dithionate	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	...	...	u[30]	Ɍ
31	Ethereal sulfates	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	...	...	U	Ɍ
32	Sulfamate, $-SO_3-NH_2^{=}$	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	...	...	u	Ɍ
33	Sulfonic acid amides	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ʉ	...	rm	Ɍ
34	Sulfoxides, R_2SO	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	u	...	u	Ɍ
35	Taurine	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	Ʉ	...	u	Ɍ
36	Thioacetamide	Ɍ	Ɍ	Ɍ	Ɍ	Ɍ	u	...	u	Ɍ

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /7/ *Synechococcus*, grown in an atmosphere of nitrogen, utilizes Na_2S (with reduction of CO_2); *Oscillatoria & Pinnularia* reduce CO_2 with H_2S, depositing sulfur in their cells; *Scenedesmus* also utilizes sulfide. H_2S toxic to *Chlorella*. /8/ Utilized (e.g., by *Beggiatoa, Thiothrix, Thioploca, Thiobacillus*). /9/ Utilized by some aquatic fungi (e.g., members of Blastocladiales and Saprolegniales which cannot utilize oxidized sulfur but require a reduced sulfur source: H_2S, cysteine, cystine, methionine, thioacetate, thiocarbonate, thioglycolate, thiourea). /10/ Utilized by *Brevilegnea gracilis;* not utilized by many other Saprolegniaceae. /11/ Utilized by *Desulfovibrio desulfuricans* and *D. aestuarii*. /12/ Utilized for formation of chondroitin sulfate and heparin; utilized by laying hens via conversion to cystine. /13/ Utilized by *Thiobacillus novellus, Pseudomonas aeruginosa, P. fluorescens*, and others. /14/ Decomposes on contact with water. /15/ Inorganic sulfur, less oxidized than sulfinate, is not efficiently utilized by *Aspergillus niger*. /16/ *Thiobacillus thiooxidans* can utilize NH_4SCN as the sole source of carbon, nitrogen and sulfur. /17/ Compound may be a sulfur source, or may be required for its molecular structure; not synthesized by the organism. /18/ Also utilize cysteic acid and isethionic acid. /19/ Utilized as nitrogen source (and sulfur source?) by *Chlorella pyrenoidosa*. /20/ Also utilize methionine sulfoxide, taurine. /21/ Numerous fungi, yeasts, bacteria, and most of the vertebrates and invertebrates studied, require biotin. The replacement of sulfur in the biotin molecule does not affect the activity for some bacteria. /22/ Complex of cysteine, glycine, and glutamic acid. /23/ Thiamine, containing pyrimidine and thiazole (the latter an imidazole ring with one carbon atom replaced by sulfur) is required by numerous organisms; probably also a sulfur source. /24/ Satisfies thiamine requirement for some (*see* Fn. 23); probably a sulfur source. /25/ Not utilized as a sulfur source by *Aspergillus niger* (cannot rupture the thiazole ring ?). /26/ Protogen, or α-lipoic acid. /27/ Required by *Tetrahymena geleii* (8 strains), and *T. vorax* (2 strains). /28/ Required by *Streptococcus faecalis* for oxidation of pyruvate. /29/ Utilized by *Penicillium brevicaule* and *Schizophyllum commune*. /30/ Not utilized by Saprolegniaceae.

continued

49. NUTRIENTS: CARBON, NITROGEN, AND SULFUR

Part III. SULFUR SOURCES

	Sulfur Source	Vertebrata	Invertebrata		Phytoflagellata (green)[2]	Algae	Bacteriophyta	Fungi		Spermatophyta
			Insecta	Protozoa[1]				Saccharomycetaceae	Other	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Miscellaneous									
37	Thioacetate	℞	℞	℞	℞	℞	u?[31]	...	r, u[9]	℞
38	Thiocarbonate	℞	℞	℞	℞	℞	...	...	r, u[9]	℞
39	Thioglycolate	℞	℞	℞	℞	℞	u?[33]	...	r, u[9]	℞
40	Thiols, R-SH	℞	℞	℞	℞	℞	...	...	u	℞
41	Thiooxalate	℞	℞	℞	℞	℞	...	...	u	℞
42	Thiourea	℞	℞	℞	℞	℞	u?[33]	u[34]	u[9]	℞
	Reference	3,26, 29,31, 41-44, 58	25,35, 59	12,27,33, 40	12,27,33, 40	11,22, 37,46, 47,51	8,10,21, 49,52,56, 57	50,54	13,14, 23,32, 38,39	1,2,4-7,9, 15-20,24,28, 30,34,36,45, 48,53,55,60

/1/ Including the colorless Phytoflagellata. /2/ Also Dinoflagellata and Chrysomonadina. /9/ Utilized by some aquatic fungi (e.g., members of Blastocladiales and Saprolegniales which cannot utilize oxidized sulfur but require a reduced sulfur source: H_2S, cysteine, cystine, methionine, thioacetate, thiocarbonate, thioglycolate, thiourea). /31/ Not utilized as carbon source by many species or strains; improbable sulfur source. /32/ Surface active in culture media for many fastidious forms. Powerful reducing agent. Not utilized as a carbon source, and improbable as a sulfur source. /33/ Utilized as a nitrogen source by many bacteria; probable sulfur source (?). /34/ Utilized by *Torula monosa and T. dattila.*

Contributors: (a) Cantino, Edward C., (b) Fogg, G. E., (c) Gordon, Harold Thomas, (d) Loefer, John B., (e) Pelletier, Réal L., (f) Turrell, Franklin M., (g) Van Wagtendonk, W. J.

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continued

49. NUTRIENTS: CARBON, NITROGEN, AND SULFUR

Part III. SULFUR SOURCES

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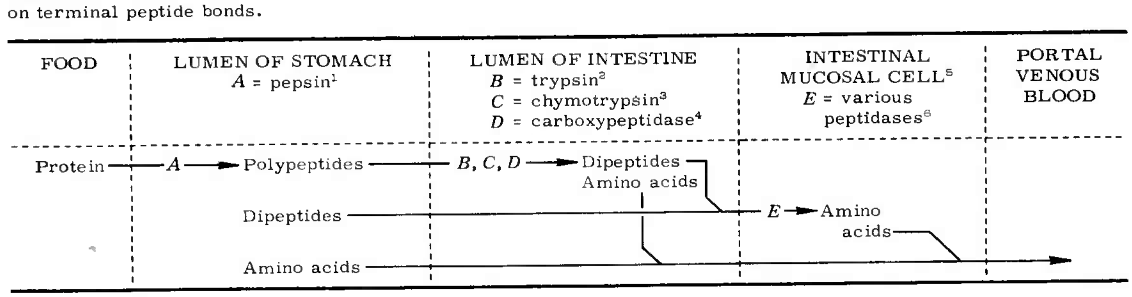
50. PATHWAYS OF PROTEIN DIGESTION: MAN AND LABORATORY MAMMALS

Pepsin, trypsin, and chymotrypsin are endopeptidases, i.e., they hydrolyze peptide bonds in the interior of peptide chains as well as terminal bonds. Carboxypeptidase and leucine aminopeptidase are exopeptidases and can act only on terminal peptide bonds.

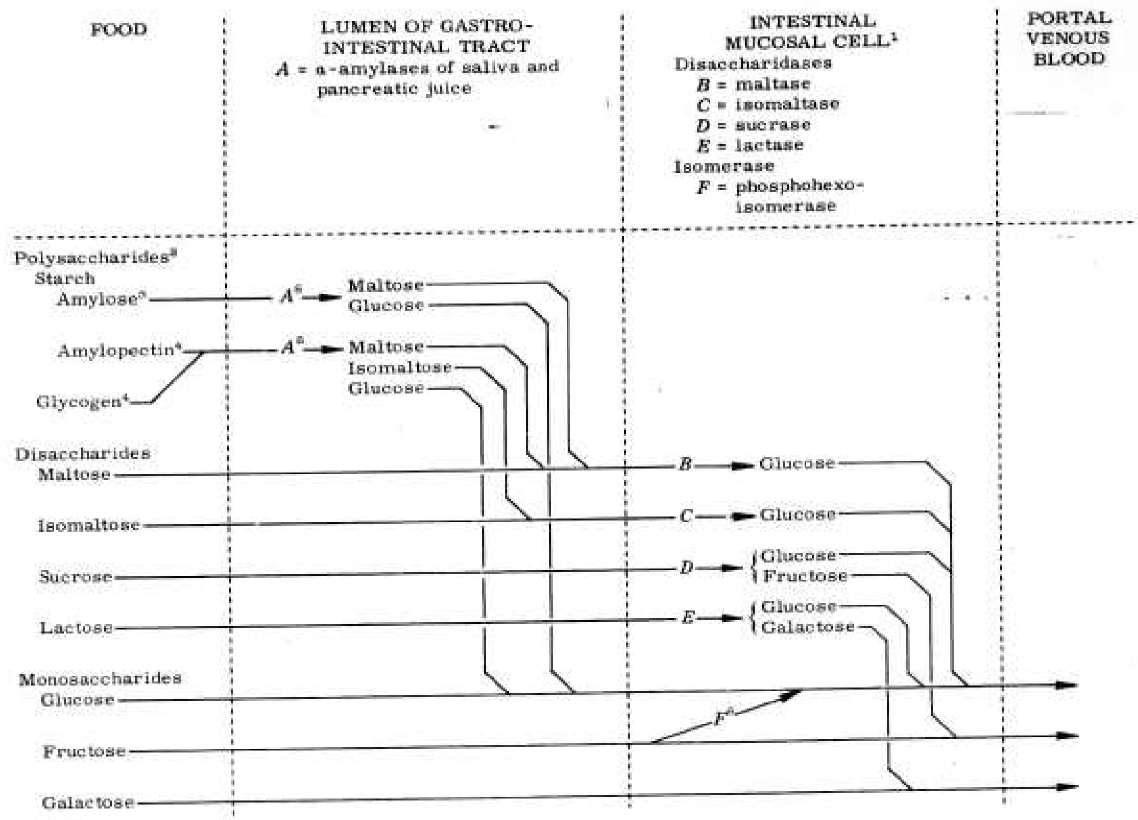


/1/ Pepsin hydrolyzes many types of peptide bonds but splits most rapidly those in which an aromatic amino acid provides the amino group. /2/ Trypsin hydrolyzes peptide bonds to which L-arginine, or L-lysine, contributes the carbonyl group. /3/ Chymotrypsin hydrolyzes many types of peptide bonds but splits most rapidly those in which an aromatic amino acid contributes the carbonyl group. /4/ Carboxypeptidase does not exhibit absolute specificity with respect to the terminal amino acid forming the bond being split; it acts most rapidly on those linkages in which aromatic amino acids are in the terminal position. The terminal amino acid must have a free carboxyl group. /5/ Amino acids and dipeptides enter the intestinal mucosal cells. Amino acids pass through unaltered--with a few exceptions, such as transamination of glutamic acid--and dipeptides are split to amino acids in the microvilli of the cell where the peptidases are localized. /6/ Only a few of the intestinal mucosal peptidases have been characterized. The best known is leucine aminopeptidase.

Contributor: Grossman, Morton I.

Reference: Fruton, J. S., and S. Simmonds. 1958. General biochemistry. Ed. 2. J. Wiley, New York.

51. PATHWAYS OF CARBOHYDRATE DIGESTION: MAN AND LABORATORY MAMMALS



/1/ Dihexoses and monohexoses are absorbed into the intestinal mucosal cell. Within the microvilli of the intestinal mucosal cell, the dihexoses are split to monohexoses. Apart from the small fraction of hexose metabolized (oxidized) during passage through the intestinal mucosal cell, phosphorylation of hexoses does not occur as a mechanism for absorption of hexoses into the cell or for delivery from the cell into the portal blood. /2/ A number of so-called structural polysaccharides occurring in foods are not digestible in the alimentary tract of vertebrates and so pass into the feces essentially unaltered. These include cellulose, lignin, mannan, xylan, pectic acids, alginic acid, and chitin. /3/ Amylose is a straight chain polymer of glucose with alpha 1-4 glucosidic linkages. /4/ Amylopectin and glycogen are branched chain polymers of glucose with alpha 1-4 linkages in the straight chain portions and alpha 1-6 linkages at the points of branching. /5/ α-Amylase hydrolyzes 1-4 glucosidic linkages in chains of glucose containing three or more residues; it does not split maltose. α-Amylase does not split the 1-6 linkages in amylopectin. /6/ Some fructose is transformed to glucose in the intestinal mucosal cell and some passes through unchanged.

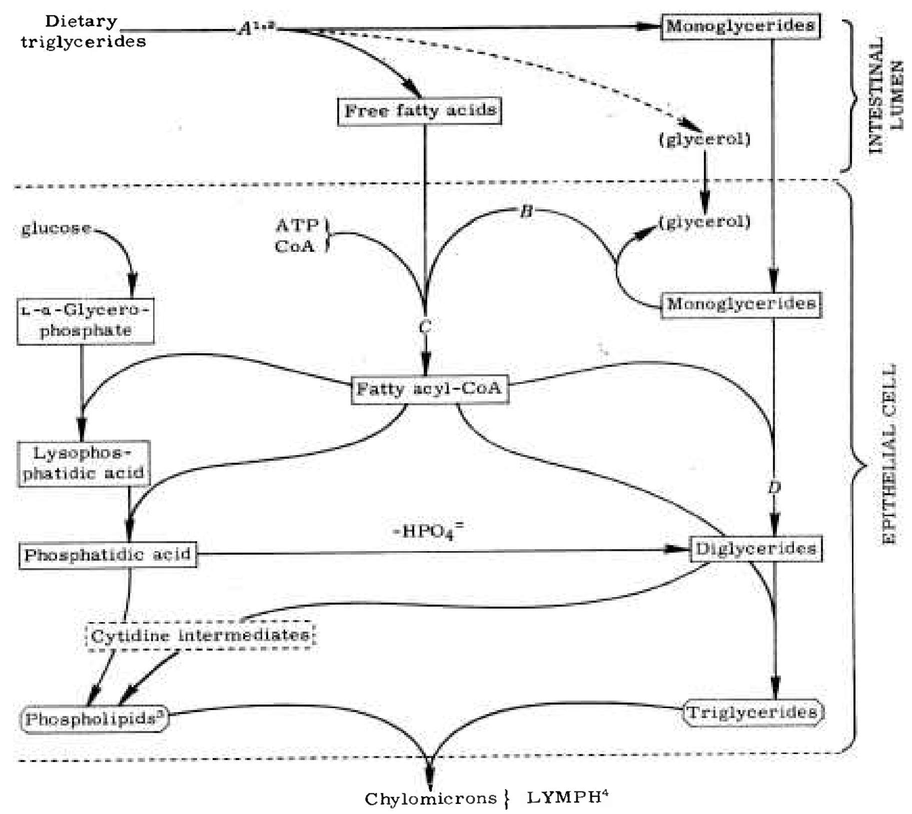
Contributor: Grossman, Morton I.

Reference: Dahlqvist, A. 1962. Gastroenterology 43:694.

52. PATHWAYS OF LIPID DIGESTION: MAN AND LABORATORY MAMMALS

ENZYME KEY

A = pancreatic lipase
B = monoglyceride lipase
C = thiokinase
D = monoglyceride acylase
ATP = adenosine triphosphate
CoA = coenzyme A



/1/ Pancreatic lipase acts preferentially on ester linkages at the terminal or 1 position of glycerol. Thus the major products of digestion are fatty acids and monoglycerides. /2/ Bile salts, in their conjugated form, participate in at least three reactions during fat digestion and absorption: (i) as a cofactor for pancreatic lipase; (ii) to form micelles containing monoglyceride and fatty acid, as well as other lipids (these micelles are probably the form in which lipid is absorbed into the cell); (iii) as a cofactor for thiokinase in the intestinal mucosal cell. /3/ Absorbed fatty acids go mainly into the triglycerides of chylomicrons, but small amounts are synthesized into cholesterol esters and phospholipids which also are constituents of chylomicrons. /4/ Fatty acids with chain lengths shorter than ten carbon atoms are absorbed mainly into the portal blood, those with longer chain lengths mainly into the lymph.

Contributor: Grossman, Morton I.

Reference: Senior, J. R., and K. J. Isselbacher. 1962. J. Biol. Chem. 237:1454.

53. EXCRETION PRODUCTS: MAN

Values are based on "normal" dietary intake, including approximately 10 grams of nitrogen per day. In reducing values to mg/kg or µg/kg, a body weight of 70 kg was assumed, unless specific weight was reported in the literature. Values in parentheses are ranges, estimate "c" (cf. Introduction).

Part I. URINE

	Constituent	Amount Excreted per kg body wt per da	Reference
	(A)	(B)	(C)
	General Chemical Components, mg		
1	Solids	860(780-1,000)	6,32,47, 82
2	Water	20,000 (7,000-42,000)	45
	Electrolytes, mg		
3	Aluminum	0.0011 (0.0007-0.0016)	41
4	Arsenic	0.00033(0-0.00130)	97
5	Bicarbonate	2.0(0.5-12.0)	27
6	Bromine	(0.012-0.110)	12
7	Calcium	3.3(0.6-8.3)	32
8	Chlorine	100(40-180)	32
9	Cobalt	0.00007 (0.00005-0.00012)	30
10	Copper	0.0005 (0.0003-0.0007)	90
11	Fluorine	0.022(0.007-0.100)[1]	32,51
12	Iodine	(0.0001-0.0070)	8
13	Iron	0.007	21
14	Lead	0.00040 (0.00016-0.00110)	41
15	Magnesium	1.35(0.42-2.40)	28
16	Manganese	(0.0001-0.0014)	41,42
17	Mercury	(0.000007-0.000010)	81
18	Nickel	(0.002-0.004)	42
	Phosphorus		
19	Inorganic P	12(10-15)	93
20	Organic P	0.131(0.089-0.187)	65
21	Potassium	34(16-56)	32
22	Selenium	0.0005(0-0.0020)	80
23	Silicon	0.13(0.06-0.20)	5
24	Sodium	60(25-94)	32
	Sulfur		
25	Total S	16.0(5.1-20.6)	23
26	Inorganic S	11.1(3.5-17.5)	23
27	Ethereal S	0.95(0.56-1.40)	23
28	Neutral S	1.90(1.05-2.60)	23
29	Tin	(0.00013-0.00025)	11,41
30	Zinc	0.018(0.011-0.033)	88
	Nitrogenous Substances, mg		
31	Protein	(0.03-1.00)	69
32	Acetylkynurenine	0.03	7
33	Adenine	0.020(0.016-0.024)	98
34	Allantoin	0.17(0.14-0.21)	100
35	Amino acids	(20-40)[2]	9
36		(13-20)[3]	9
37	Alanine	0.55[2]	9
38	β-Alanine	(0.2-0.3)	13
39	Arginine	0.45(0.34-0.50)[2]	89
40		0.16(0.07-0.30)[3]	89
41	Asparagine	0.77	78
42	Aspartic acid	1.7(1.2-2.7)[2]	102
43		0.04(0.01-0.07)[3]	102

	Constituent	Amount Excreted per kg body wt per da	Reference
	(A)	(B)	(C)
	Amino acids		
44	Citrulline	0.09(0-2.8)	103
45	Cystine	1.7(1.0-2.6)[2]	85
46		1.3(0.6-1.9)[3]	75
47	Glutamic acid	(3.7-5.0)[2]	9,33
48		0.8(0-1.5)[3]	9,33
49	Glycine	6.5[2]	20
50		2.2[3]	9
51	Histidine	2.7(1.0-5.0)[2]	9,85,102
52		2.0(1.2-2.7)[3]	9,102
53	Hydroxyproline	0.02[2]	9
54	Isoleucine	0.2(0.1-0.3)[2]	20,75,102
55		0.08(0.04-0.20)[3]	20,75,102
56	Leucine	0.30(0.22-0.45)[2]	20,75,102
57		0.13(0.05-0.17)[3]	20,75,102
58	Lysine	0.80(0.48-1.70)[2]	20,75,102
59		0.40(0.17-0.67)[3]	20,33,75
60	Methionine	0.14(0.10-0.17)[2]	20,75,102
61		0.05(0.03-0.10)[3]	20,75,102
62	1-Methylhistidine	Trace[4]	83
63	3-Methylhistidine	Trace[4]	83
64	Ornithine	0.15	9
65	Phenylalanine	0.30(0.21-0.54)[2]	9,20,102
66		0.17(0.09-0.23)[3]	9,20,102
67	Proline	0.61(0.30-0.90)[2]	102
68		0.12(0.03-0.20)[3]	102
69	Serine	0.6(0.5-0.7)[2]	9,94
70		0.3(0.2-0.5)[3]	9,94
71	Taurine	(0.11-0.20)	103
72	Threonine	0.50(0.36-2.60)[2]	9,20,75, 94,102
73		0.25(0.11-0.35)[3]	9,20,75, 94,102
74	Tryptophan	0.40(0.23-0.70)[2]	94,102
75		0.20(0.11-0.36)[3]	94,102
76	Tyrosine	0.70(0.44-0.82)[2]	85,94,102
77		0.20(0.15-0.30)[3]	85,94,102
78	Valine	0.30(0.25-0.42)[2]	20,75,94
79		0.09(0.04-0.18)[3]	20,75,94
80	*o*-Aminohippuric acid	0.06	7
81	Anthranilic acid	(0.002-0.009)	1
82	Bilirubin	0.70	58
83	Carnosine (+ anserine)	(0.045-0.14)	13
84	Coproporphyrin I & III	(0.00024-0.00400)	96
85	Creatine	0.8(0-2.0)	89
86	Creatinine	23(15-30)	89
87	1,3-Dimethyluric acid	Trace	17
88	Dopamine	(0.0041-0.0063)	3
89	Epinephrine	0.00014	92
90	Ergothionine	(1.7-4.0)	60
91	Ethanolamine	(0.07-0.7)	49
92	Guanidinoacetic acid	(0.2-0.5)	89
93	Guanine	0.006(0.003-0.009)	98
94	Hippuric acid	(7.0-18.0)	101
95	Histamine	(0.00025-0.001)	39,71

/1/ Upper limit of range was obtained in an area of Texas where dental fluorosis is endemic. /2/ Total. /3/ Free. /4/ Determined by chromatography.

continued

53. EXCRETION PRODUCTS: MAN

Part I. URINE

	Constituent (A)	Amount Excreted per kg body wt per da (B)	Reference (C)
	Nitrogenous Substances, mg		
96	3-Hydroxyanthranilic acid	(0.008-0.04)	1
97	*p*-Hydroxybenzylamine	0.002	39
98	5-Hydroxyindoleacetic acid	(0.02-0.03)	101
99	3-Hydroxykynurenine	0.075	7
100	8-Hydroxy-7-methylguanine	0.020(0.016-0.030)	98
101	*p*-Hydroxyphenylacetic acid	(0.2-1.2)	101
102	Hypoxanthine	0.14(0.08-0.19)	98
103	Imidazole derivatives	(2-3)	44
104	Indoleacetic acid	(0.02-0.06)	101
105	Indoxylsulfuric acid[5]	1.0(0.5-2.0)	74
106	Kynurenic acid	0.03	7
107	Kynurenine	(0.023-0.078)	1
108	Metanephrine	(0.002-0.006)	39
109	Methionine sulfoxide	(0-0.31)	9,103
110	3-Methoxytyramine	(0-0.0005)	39
111	7-Methylguanine	0.09(0.08-0.11)	98
112	N^2-Methylguanine	0.007(0.006-0.009)	98
113	1-Methylhypoxanthine	0.006(0.003-0.010)	98
114	*N*-Methyl-2-pyridone-5-carboxamide	0.24	7
115	Norepinephrine	0.001	92
116	Normetanephrine	(0.0002-0.0005)	39
117	Purine bases	(0.2-1.0)	32
118	Serotonin	(0.00025-0.001)	39
119	6-Succinopurine	0.014	99
120	Theophylline	Trace	17
121	Tryptamine	(0.0013-0.0028)	63
122	*m*-Tyramine	(0.001-0.0025)	39
123	*p*-Tyramine	(0.0005-0.0025)	39
124	Urea	(200-500)	32
125	Uric acid	2.0(0.8-3.0)	32
126	Urobilin	(0.143-1.857)	46
127	Urobilinogen	(0.043-0.357)	46
128	Xanthine	0.09(0.07-0.12)	98
129	Xanthurenic acid	0.02	7
	Nitrogen		
130	Total N	(130-300)	32
131	Amino acid N	(3-6)	31
132	Ammonia N	(3-13)	95
133	Protein N	(0.0046-0.0180)	95
	Lipids, Carbohydrates, Miscellaneous Organic Acids, mg		
134	Aconitic acid	Trace	29
135	Cholesterol	(0-0.0714)	54
136	Homovanillic acid	(0.065-0.110)	101
137	3-Methoxy, 4-hydroxymandelic acid	0.053	92
138	Reducing substances	(7-21)	6
139	Acetone bodies	0.20(0.03-0.30)[2]	77
140	Acetoacetic acid	0.04(0.03-0.06)	77
141	Carbolic acid[6]	(0.2-0.6)[2]	15
142		(0-0.05)[3]	15
143	Carbonic acid	2.7(2.1-3.3)	27

	Constituent (A)	Amount Excreted per kg body wt per da (B)	Reference (C)
144	Citric acid	(3-20)	84
145	Formic acid	0.8(0.4-2.0)	4
146	Lactic acid	3(2-5)	26
147	Oxalic acid	0.5(0.3-0.7)	32
148	Arabinose	Trace[4]	87
149	Deoxyribose	Trace[4]	87
150	Galactose	Trace[4]	87
151	Glucose	Trace[4]	87
152	Glucuronic acid	Trace[4]	87
153	Lactose	Trace[4]	87
154	Ribose	Trace[4]	87
155	Ribulose	Trace[4]	25
156	Xylose	Trace[4]	25
157	Xylulose	Trace[4]	86
	Vitamins and Related Compounds, µg		
158	Vitamins A, D, K	(0-trace)	82
159	*p*-Aminobenzoic acid	(2-3)	16
160	Ascorbic acid	(100-400)	10
161	Biotin	0.5(0.2-1.0)	16
162	Choline	79(68-130)	36
163	Citrovorum factor	0.037(0.023-0.069)	68
164	Cyanocobalamin	0.00044 (0.00023-0.00079)	68
165	Inositol	200	38
166	Nicotinic acid[7]	3.4(2.0-20.0)	16,37
167	Nicotinamide[8]	20(10-50)	16,37
168	Pantothenic acid	45(16-100)	16
169	Pteroylglutamic acid[9]	0.058(0.030-0.300)	16,68
170	Pyridoxine	(0.08-2.70)	35
171	Riboflavin	12.4(2.0-24.0)	16,61
172	Thiamine	3.0(0.6-6.0)	16
173	Dehydroascorbic acid	(190-290)	10
174	Dehydroascorbic + diketogulonic acid	230(0-1,280)	24
175	Diketogulonic acid	(140-190)	10
176	*N*-Methylnicotinamide	(40-600)	16,37
177	Pyridoxal	1.0(0.7-5.3)	35,64
178	Pyridoxamine	1.6(0.4-3.0)	64
179	4-Pyridoxic acid	(9-160)	35,64
180	Trigonelline	(30-300)	62
	Hormones, µg		
	Aldosterone		
181	♂	0.05(0.01-0.13)	91
182	♀	0.06(0.03-0.10)	91
	Androgens		
183	♂, 3-5 yr	210	19
184	♂, 20-40 yr	260(200-330)	19
185	♂, 60+ yr	70(30-130)	19
186	♀, 3-5 yr	50	19
187	♀, 20-40 yr	200(180-210)	19
188	♀, 60+ yr	40(15-130)	19
	Androsterone		
189	♂	50(35-60)	73
190	♀	60(50-80)	73
	Etiocholanolone		
191	♂	60(40-70)	73
192	♀	50(30-60)	73
	Estradiol		
193	♀, follicular phase	0.03(0-0.05)	70

/2/ Total. /3/ Free. /4/ Determined by chromatography. /5/ Indican. /6/ Phenol. /7/ Niacin. /8/ Niacinamide. /9/ Folic acid.

continued

53. EXCRETION PRODUCTS: MAN

Part I. URINE

	Constituent	Amount Excreted per kg body wt per da	Reference
	(A)	(B)	(C)
	Hormones, µg		
	Estradiol		
194	♀, luteal phase	0.10(0.07-0.17)	70
195	♀, postmenopause	0.01(0-0.09)	50
	Estriol		
196	♀, follicular phase	0.1(0-0.3)	70
197	♀, luteal phase	0.40(0.13-1.30)	70
198	♀, postmenopause	0.05(0-0.18)	50
	Estrone		
199	♀, follicular phase	0.08(0.06-0.12)	70
200	♀, luteal phase	0.20(0.17-0.40)	70
201	♀, postmenopause	0.03(0-0.12)	50
	17-Hydroxysteroids		
202	♂	80(40-170)	66,67
203	♀	60(20-140)	66,67
	17-Ketogenic adrenocorticoids		
204	♂	210(150-310)	18
205	♀	180(120-300)	18
206	α-Ketol steroids	260(130-470)	53
	Pregnanediol		
207	♂	13(5-20)	43
208	♀, follicular phase	18(13-25)	43
209	♀, luteal phase	55(30-70)	43
	Pregnanediol		
210	♀, postmenopause	10(5-14)	43
	Pregnanetriol		
211	♀, follicular phase	25	79
212	♀, luteal phase	32	79
213	♀, postmenopause	11	79
214	Tetrahydrocortisol	24(8-50)	70
215	Tetrahydrocortisone	54(20-120)	70
216	Adrenocorticotropin	Consult references	72
217	Insulin		57
218	Melanocyte-stimulating hormone		76
219	Parathyroid hormone		14
	Enzymes		
220	Acid phosphatase	Consult references	2
221	Amylase		52
222	Cadaverinase		40
223	Cathepsin		56
224	β-Glucuronidase		55
225	Histaminase		40
226	Lipase		59
227	Maltase		22
228	Ribonuclease		48
229	Uropepsinogen		34

Contributor: Van Pilsum, John F.

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continued

53. EXCRETION PRODUCTS: MAN

Part II. FECES

	Constituent	Amount Excreted per kg body wt per da	Reference
	(A)	(B)	(C)
	General Chemical Components, mg		
1	Solids	394(140-560)	26
2	Water	(910-1,820)	21
	Electrolytes, mg		
3	Aluminum	0.0006	10
4	Arsenic	0.033(0.001-0.116)	17
5	Calcium	(5-10)	19
6	Chlorine	(0.21-0.50)	1
7	Cobalt	(0.000002-0.000020)	8
8	Copper	0.027(0.023-0.037)	10
9	Iron	120(65-208)	4
10	Lead	0.0042	10
11	Magnesium	2.5(1.510-3.185)	13
12	Manganese	(0.018-0.120)	10,11
13	Mercury	0.00014	20
14	Nickel	(0.0012-0.0025)	11
15	Phosphorus	0.00986 (0.00710-0.0200)[1]	4
16	Potassium	6.7	3
17	Silver	0.0008	10
18	Sodium	1.7	3
19	Sulfur	2.0[1]	3
20	Tin	(0.17-0.45)	3,10
21	Zinc	0.100(0.058-0.144)	22
	Nitrogenous Substances, mg		
	Amino acids		
22	Arginine	3.8(2.9-5.0)[1]	18
23	Histidine	1.7(1.4-2.1)[1]	18
24	Isoleucine	4.3(3.3-5.5)[1]	18
25	Leucine	5.6(4.3-6.9)[1]	18
	Amino acids		
26	Lysine	5.7(4.5-6.9)[1]	18
27	Threonine	4.0(3.3-5.2)[1]	18
28	Valine	4.6(3.6-6.2)[1]	18
29	Imidazole derivatives	(0-0.2)	14
30	Purine bases	(2-3)	15
31	Urobilinogen	(0.00057-0.00400)	24
	Nitrogen		
32	Total N	(11.4-36.0)	9
33	Ammonia N	(0.36-1.20)	16
	Lipids and Miscellaneous Organic Acids, mg		
	Fat		
34	Total	56(30-100)	26
35	Neutral	(10-45)	7
36	Unsaponifiable	33(22-38)[2]	25
37	Fatty acids	16(4-38)[1]	7
38		30(4-64)[3]	7
39	Soaps	53(40-66)[2]	25
40	Carbolic acid	(0-3)[1]	6
	Vitamins and Related Compounds, µg		
41	*p*-Aminobenzoic acid	3.50(1.01-8.20)	5
42	Ascorbic acid	(60-70)	2
43	Biotin	1.90(0.63-6.64)	5
44	Vitamin E	308(226-391)	12
45	Nicotinic acid	52(12-124)	5
46	Pantothenic acid	31.40(3.85-63.40)	5
47	Pteroylglutamic acid	4.3(1.8-7.7)	5
48	Riboflavin	14.7(8.0-23.0)	5
49	Thiamine	7.80(0.67-18.00)	5
50	Carotene + xanthophyll	(20-600)	23
51	Xanthophyll	(8-100)	23

/1/ Total. /2/ At age 8-12 years. /3/ Free.

Contributor: Van Pilsum, John F.

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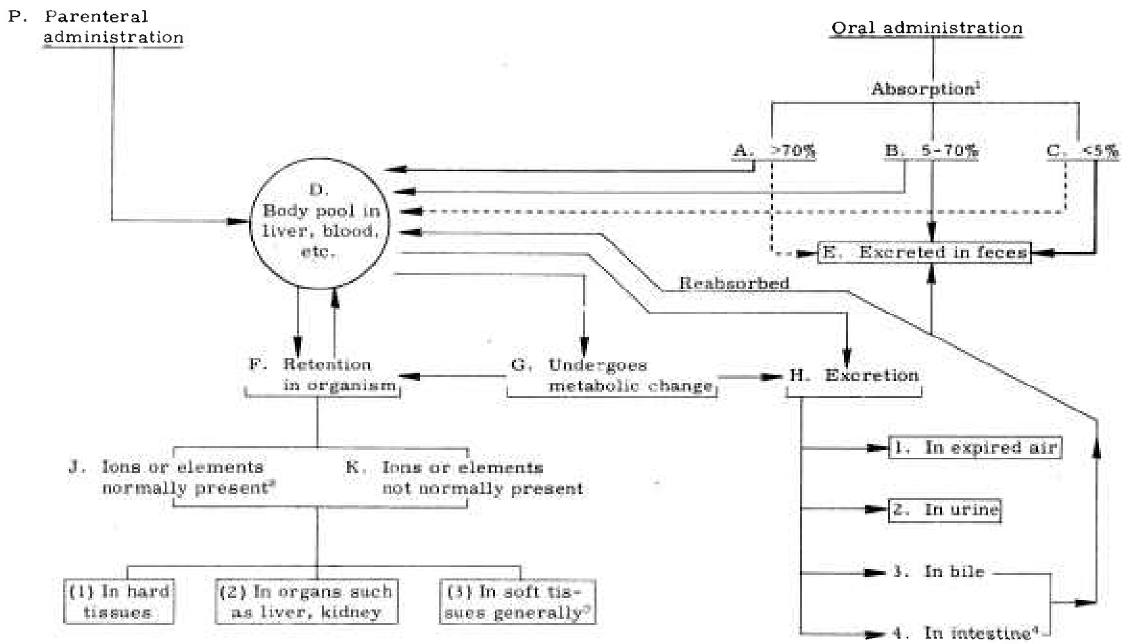
VI. METABOLISM

DIAGRAM FOR TABLE 54



/1/ Percent absorption from oral administration has in some cases been rather arbitrarily classified, since the extent of absorption may depend on the amount administered and on the presence or absence of food residues in the digestive tract. /2/ Some trace elements with no known function also included. - /3/ Primarily muscle, skin, and extracellular fluids. /4/ Other than in the bile, or by a route not definitely established.

54. PATHWAYS OF MINERAL METABOLISM: LABORATORY MAMMALS

The course, or courses, of various ions during metabolism can be located in the diagram (at left) by tracing the combination of letters and numbers accompanying each ion (columns B and C below). Observations were made on a wide variety of mammalian species. Ions were administered in the form of simple soluble compounds or metallic oxides, unless otherwise specified. Underscoring indicates radioactive elements, or that data were obtained at least in part from studies using radioactive isotopes. Different isotopes of the same element may show different tissue predilections, but there is usually no difference in their absorption or route of excretion. "Plus" symbols indicate valence states to which data apply. **Other Known Pathways** (column C) are listed, so far as possible, in order of decreasing importance.

	Ion	Principal Oral Pathways[1]	Other Known Pathways	Reference
	(A)	(B)	(C)	(D)
			Cations[2]	
1	Actinium	CE	PDFK(1, 2)	10
2	Aluminum	CE	PDH2, PDH3, PDFJ(2)	40,91,93
3	Americium	CE	PDH4, PDFK(2, 1), PDH2	88,102
4	Antimony^{+++}	BE, BDH2	BDFK(2, 3), BDH4	31,34,40,93
5	Arsenic^{+++}	BE, BDH2	BDFK(2, 3), BDH4	16,40,54,58,93
6	Barium	BE, BDH4	BDFK(1), BDH2	12,36,69,93,102
7	Beryllium	CE	PDFK(1, 3, 2), PDH2, PDH4	83,93
8	Bismuth^{+++}	CE	PDFK(2), PDH4, PDH2	40,57,93
9	Cadmium	CE	PDFK(2, 3, 1), PDH4, PDH2	20,23,40,78,93,110
10	Calcium	BE, BDFJ(1)	BDH4, BDH3, BDH2, BDFJ(3)	3,19,40,75,92,97,103,110,111
11	Cerium[3]	CE	PDFK(2, 1), PDH3, PDH2	23,24,40,46,94,102
12	Cesium	ADH2	ADH3, ADH4, ADFJ(3)	36,52,71-74,90,93
13	Chromium^{+++}	CE	PDH2, PDH4, PDFK(2, 1)	23,25,50,106
14	Cobalt^{++}	BE, BDH2	BDH3, BDH4, BDFJ(2)	5,17,19,40,56,93,110
15	Copper^{++}	BE—BDH3	BDH2, BDFJ(2)	19,40,64,93,110
16	Curium	Probably CE[4]	PDFK(2, 1), PDH4, PDH2	86, 102
17	Dysprosium[3]	....	PDH3, PDFK(1)	24
18	Erbium[3]	....	PDH3, PDFK(1, 2)	24
19	Europium[3]	CE	PDH3, PDH2, PDFK(1, 2)	24
20	Francium	Probably ADH2[4]	PDFK(2, 3)	76
21	Gadolinium[3]	....	PDH2, PDH3, PDFK(1, 2)	24
22	Gallium	CE	PDH2, PDFK(1, 2), PDH4	22,53,93
23	Germanium	ADH2	ADH4, ADFK(2)	93
24	Gold^{+++}	CE	PDFK(2), PDH2, PDH4	34,40,79,93
25	Hafnium[3]	....	PDFK(2, 1), PDH2, PDH4	47,93
26	Holmium[3]	....	PDH3, PDFK(1, 2)	24
27	Indium	CE	PDFK(3, 1, 2), PDH4, PDH2	23,39
28	Iridium	CE	PDH2, PDH4, PDFK(3, 2, 1)	23
29	Iron^{++}	CE	PDH4, PDFJ(2)	19,40,65,93,110,111
30	Lanthanum[3]	CE	PDH2, PDH3, PDFK(2, 1)	13,23,24,36,40,93,95,102
31	Lead^{++}	BE, BDH4	BDH2, BDFK(1, 3, 2)	1,9,23,34,35,40,57,82,93
32	Lithium	ADH2	ADH4, ADFJ(3, 2)	30,35,81,93
33	Lutetium[3]	....	PDH3, PDFK(1)	24
34	Magnesium	BE, BDH2	BDH3, BDFJ(1, 2, 3)	2,40,91,93,110
35	Manganese^{++}	CE	PDH3, PDH4, PDFJ(2, 3)	8,19,28,40,60,66,93
36	Mercury^{++}	BE, BDH2	BDFK(1, 2, 3), BDH3, BDH4	23,40,93
37	Neodymium[3]	Probably CE[4]	PDH2, PDFK(2, 1), PDH3	23,24,38,40,55
38	Neptunium	CE	PDFK(1)	36
39	Nickel^{++}	BE, BDH2	BDH4, BDFJ(2)	5,35,40,93,98,108,110
40	Niobium[3]	CE	PDH2, PDH4, PDFK(2, 1, 3)	13,23,36,80,102
41	Palladium	Probably CE[4]	PDH2, PDH4, PDFK(2)	23,40,67
42	Platinum	CE	PDH2, PDH4, PDFK(2, 3, 1)	23,40
43	Plutonium[3]	CE	PDFK(1, 2), PDH4, PDH2	11,29,36,84,89,102,109
44	Polonium	CE	PDFK(2, 1, 3), PDH4, PDH2	27,44,93,96,102

/1/ Ions may be assumed to follow the same pathways when given parenterally. /2/ Because of inadequate information, no pathways have been listed for berkelium, californium, einsteinium, fermium, and mendelevium. /3/ Usually given as soluble complex. /4/ As judged from the position of the element in the periodic table, or on solubility at neutral pH values.

continued

54. PATHWAYS OF MINERAL METABOLISM: LABORATORY MAMMALS

	Ion	Principal Oral Pathways[1]	Other Known Pathways	Reference
	(A)	(B)	(C)	(D)
	Cations			
45	Potassium	ADH2	ADFJ(3,2), ADH3, ADH4	18,19,40,71,73,103
46	Praseodymium[3]	CE	PDH2, PDFK(2,1), PDH3	24,36,40
47	Promethium	CE	PDH2, PDFK(2,1), PDH3	24,36,102
48	Protactinium	Probably CE[4]	PDFK(1)	88
49	Radium	BE, BDFK(1,2)	BDH4, BDH2	27,45,75,93,97,102
50	Radium D	Probably BE, BDH2[4]	PDH2, PDH4, PDFK(1)	9,70
51	Rhodium	CE	PDFK(3,2,1), PDH2, PDH4	23
52	Rubidium	ADH2	ADFJ(3,2), ADH3, ADH4	68,71
53	Ruthenium	CE	PDH2, PDH4, PDFK(3,1,2)	23,100,101
54	Samarium[3]	CE	PDH2, PDFK(2,1), PDH3	23,40
55	Scandium	Probably CE[4]	CDH2, CDFJ(1,3)	4
56	Selenium	ADH2	ADGH1, ADFK(2,3), ADH4	61,62,93
57	Silver	CE	PDH3, PDFK(2,3), PDH2, CDGFK[5]	40,87,93,110
58	Sodium	ADH2	ADFJ(3,1,2), ADH3, ADH4	19,40,91,93
59	Strontium	BE, BDFK(1)	BDH2, BDH4, BDH3	3,36,45,75,92,102,103
60	Tantalum	CE	PDH2, PDH4, PDFK(2,1,3)	23,24
61	Technetium	....	PDH2, PDH4, PDFK(3,2,1)	23
62	Tellurium++++	BE, BDGH2	BDGH3, BDGH1, BDGFK(2)	36,93,102
63	Terbium[3]	CE	PDH2, PDH3, PDFK(1,2)	24
64	Thallium	BE	BDH4, BDFK(3,1,2), BDH2	40,59,93
65	Thorium	CE	PDFK(2,1), PDH4, PDH2, PDH3	36,85,93,102
66	Thulium[3]	CE	PDH2, PDH3, PDFK(1)	24
67	Tin++	BE, BDH2	BDFJ(3,2), BDH4, BDH3	40,93,110
68	Tin++++[3]	BE, BDH2	BDH4, BDFJ(1,3,2)	23
69	Titanium	Probably CE[4]	CDFJ(2)	93
70	Uranium++++	....	BDFK(2)	102
71	Uranium++++++	BE, BDH2	BDFK(1,2)	21,40,93,102
72	Ytterbium[3]	....	PDH3, PDFK(1,2)	24
73	Yttrium	CE	PDFK(1,2), PDH2, PDH4	13,24,32,36,46,84,102,109
74	Zinc	CE	CDH4, CDFJ(2,3), CDH2	33,40,60,77,93,102-105,110
75	Zirconium	CE	PDFK(1,3)	13,36,80,102
	Anions[6]			
76	Astatide	Probably A[7]	PDFK(3), PDH2, PDH4	37
77	Bicarbonate	ADH1, ADH2, ADH3	ADH4, ADFJ (all tissues)	93
78	Borate	ADH2	....	40,93
79	Bromate	ADH2	ADG (to bromide)	41,93
80	Bromide	ADH2	ADH3, ADH4, ADFJ(3)	14,93
81	Chlorate	ADH2	....	40,93
82	Chloride	ADH2	ADH3, ADH4, ADFJ(3,1,2)	91,93
83	Chromate	BDH2	BDH4, BDGH2, BDGH1, BDGFK(2)	40,63,93,106
84	Cyanide	ADH2	ADH1, ADG (to SCN^-)	93
85	Ferrocyanide	ADH2	....	48,49,93
86	Fluoride	BDH2	BDFJ(1,3), BDH4	60,91,93
87	Hypophosphite	ADH2	....	93
88	Iodate	ADG (to iodide)	PDH2	93
89	Iodide	ADH2	ADFJ(3,2), ADH3	93
90	Molybdate	BDH2	BDFJ(2,3,1)	7,15,24,35,40,99,102
91	Nitrate	ADH2	ADFK(3)	93
92	Nitrite	ADG (to nitrate)	....	93
93	Osmate	....	PDH2, PDH4, PDFK(3,2,1)	23
94	Oxalate	ADH2	....	93
95	Perchlorate	ADH2	....	41
96	Permanganate	CE (reduced to MnO_2)	....	41
97	Perrhenate	CE	PDH2, PDFK(3)[5], PDH4	23,43
98	Phosphate	BE, BDH2	BDFJ(1,2,3), BDH3, BDH4	19,93
99	Silicate	BE, BDH2	BDFJ(2)	34,35,42,91,93
100	Sulfate	BE, BDH2	BDH3, BDH4, BDG	19,26,51

/1/ Ions may be assumed to follow the same pathways when given parenterally. /3/ Usually given as soluble complex. /4/ As judged from the position of the element in the periodic table, or on solubility at neutral pH values. /5/ Skin. /6/ Because of inadequate information, no pathways have been listed for cyanate, ferricyanide, and periodate. /7/ As judged from solubility at neutral pH values.

continued

54. PATHWAYS OF MINERAL METABOLISM: LABORATORY MAMMALS

	Ion	Principal Oral Pathways[1]	Other Known Pathways	Reference
	(A)	(B)	(C)	(D)
			Anions	
101	Sulfide	ADG (to sulfate)	ADH1	93
102	Thiocyanate	ADH2	ADFK(3), ADH3, ADH4	93
103	Thiosulfate	BE, BDG (to sulfate)	PDH2	93
104	Tungstate	BE, BDH2	BDFK(3,1,2), BDH4	24,40,107
105	Vanadate	ADH2	ADFJ(2), ADH4	6,40,93

/1/ Ions may be assumed to follow the same pathways when given parenterally.

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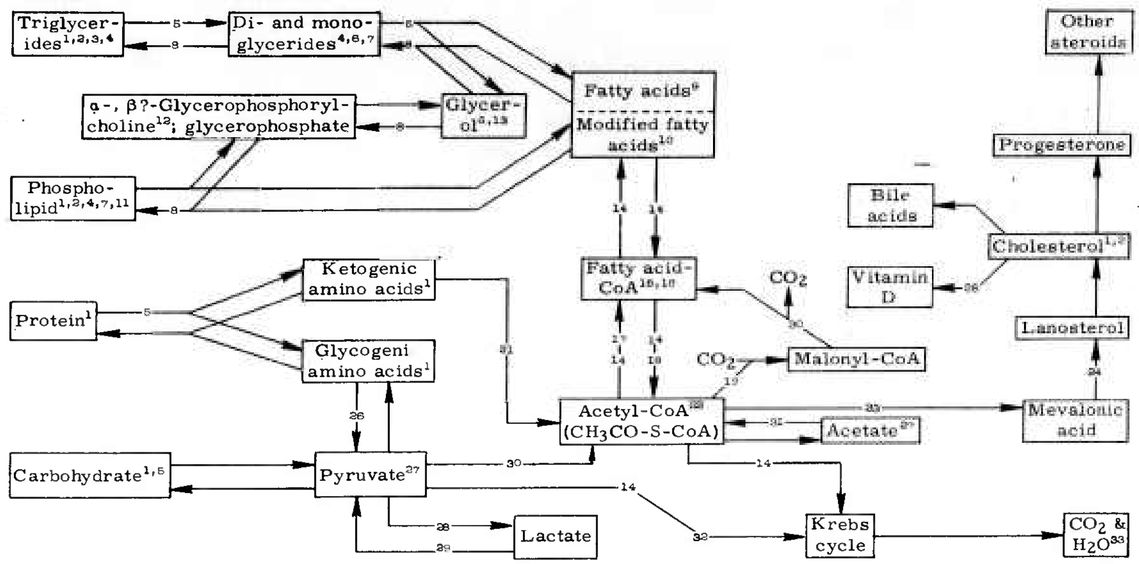
55. PATHWAYS OF LIPID METABOLISM: MAMMALS

Pathways are based on studies confined chiefly to mammals.



/1/ In intestinal lumen, blood, liver, other tissues. /2/ In chyle. /3/ Absorption by intestinal mucosa questionable. /4/ Formed in intestinal mucosa, or absorbed from lumen; pass into chyle. Short chains possibly also pass into portal blood. /5/ Digestion in intestinal lumen. /6/ Probably transitory in tissues. /7/ Some absorption by intestinal mucosa. /8/ In intestinal mucosa, liver, other tissues. /9/ Occur free (ionized) in intestinal lumen, blood, liver, but certain unsaturated fatty acids must be obtained from the diet. Free existence in chyle questionable; probably transitory if free existence occurs in other tissues. /10/ In liver, carbon chains are lengthened or shortened (*see* footnote 18), and H is added to C_{9-10}, or removed creating double bonds. /11/ Chiefly lecithin, cephalins (phosphatides of ethanolamine, serine, inositol, acetal, polyglyceride), and some sphingomyelin. /12/ In intestinal mucosa, liver (?), and other tissues (?). Split to choline, glycerol, phosphoric acid. /13/ In intestinal lumen; absorbed by intestinal mucosa and resynthesized into glycerides, including phospholipids. Metabolized to pyruvate. /14/ In liver and other tissues. /15/ Fatty acid ester of CoA (i.e., acyl-CoA ester) is formed by ATP-dependent acylation of CoA, or by transfer of CoA from succinyl- or other CoA ester. /16/ CoA = pantetheine (pantoic acid + β-alanine + thioethanolamine) + ADP, with a third PO_4 at the ribose; forms fatty acid thiol esters via the SH in thioethanolamine. /17/ Reverse of β-oxidation (*see* Fn. 18); NADPH required; mitochondrial pathway. /18/ Fatty acid ester of CoA is shortened 2 carbons at a time by β-oxidation, breaking off a molecule of acetyl-CoA at each step and re-esterifying the remainder with CoA. /19/ Biotin-dependent carboxylation to malonyl CoA. /20/ 7 acetyl → 7 malonyl, then 1 acetyl + 7 malonyl → 1 palmityl-CoA; NADPH required; extra mitochondrial pathway. /21/ Tyrosine, leucine, and isoleucine also converted directly to acetoacetate. /22/ Acetic acid ester of CoA known also as *S*-acetyl-CoA, active acetyl. /23/ Through intermediates--acetoacetyl-CoA, β-hydroxy-β-methyl-glutaryl-CoA, and mevaldic acid. /24/ Through intermediates--farnesel and squalene. /25/ Requires light. /26/ Aspartate enters Krebs cycle not via pyruvate, but by conversion directly to oxalacetate. /27/ Occurs in blood, liver, muscle, other tissues. /28/ Occurs in muscle, especially in exercise, the lactate diffusing into the blood stream. /29/ Occurs in liver, muscle, brain, and other tissues. /30/ Diphosphothiamine (cocarboxylase), lipoic acid, Mg^{++}, and NAD^+ required. /31/ ATP-dependent reaction with CoA. /32/ Pyruvate + CO_2 → oxalacetate, and malate, components of Krebs cycle. Oxalacetate condenses with acetyl-CoA, to form citrate. This removal of acetyl-CoA by oxalacetate (i.e., by pyruvate), occurring when acetyl-CoA is being formed in active fat catabolism, may explain antiketogenic action of carbohydrate (and protein). /33/ And energy liberation.

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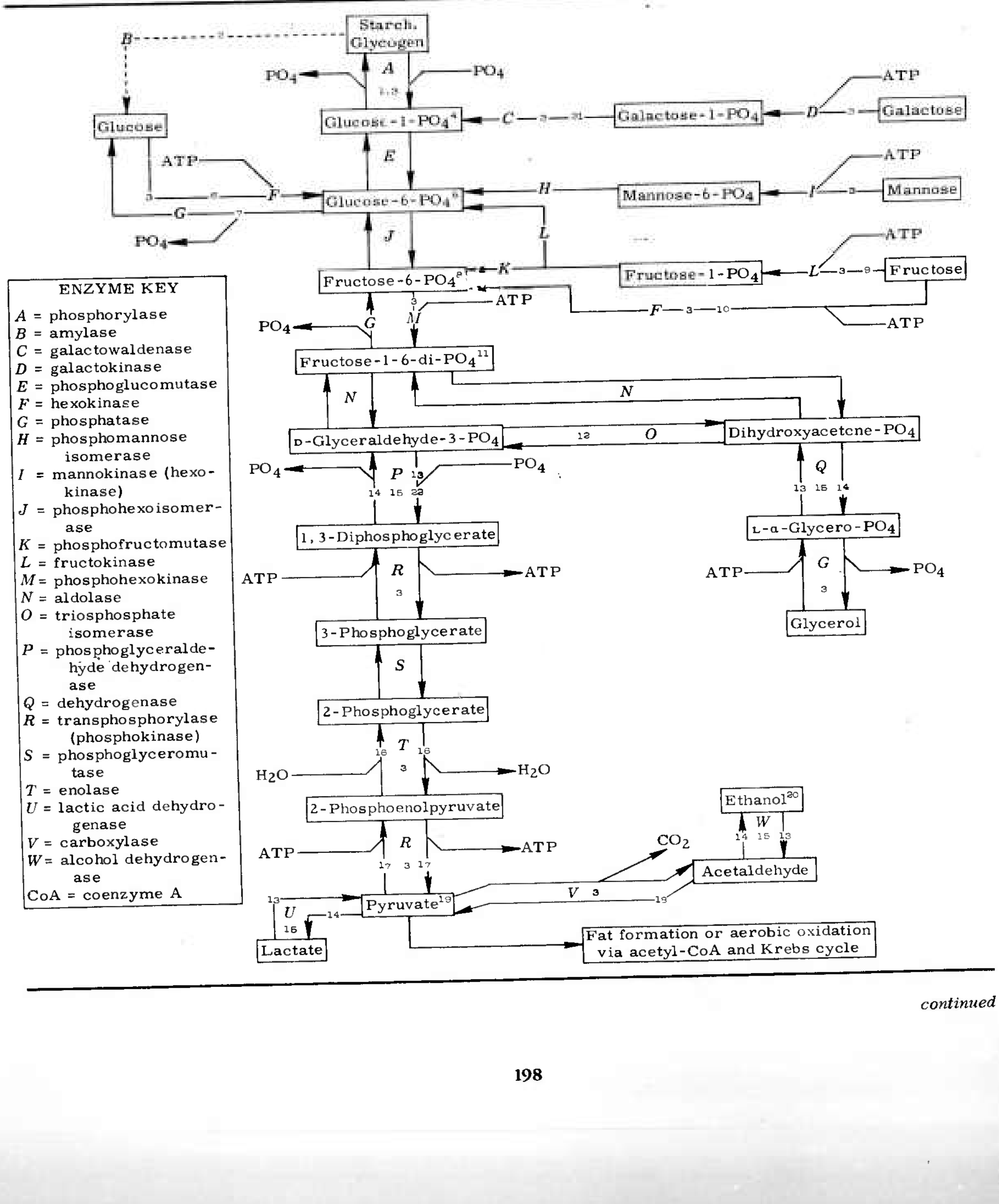
56. PATHWAYS OF CARBOHYDRATE METABOLISM

The conversion of stored or ingested carbohydrate to pyruvate releases stored energy by means of anaerobic oxidation (glycolysis). Released energy is partly dissipated as heat and partly stored (temporarily) in the labile energy pool as high-energy phosphate (-PO_4) by combination of -PO_4 with continuously available ADP (adenosine diphosphate) to form ATP (adenosine triphosphate). In the conversion of 1 mole of glucose (180 g), or of other monosaccharides, to 2 moles of pyruvate (174 g), 2 moles of ATP are converted to ADP and 4 moles of ATP are formed from ADP, making a net gain of 2 moles of ATP, or approximately 14 kilocalories of readily available energy. If glucose-6-PO_4 has come from the metabolic breakdown of glycogen, the cost is only 1 mole of ATP, making a net gain of 3 moles of ATP (approximately 21 kilocalories). The ATP is an immediate source of energy, the utilization of which (e.g., for muscular activity) is independent of oxygen supply. Aerobic oxidation of the reduced coenzymes formed in glycolysis and in the Krebs cycle yields considerable amounts of energy. The reactions may be summarized as follows: glucose + 2 ATP → 2 pyruvate + 8 ATP; 2 pyruvate → 2 acetyl CoA + 6 ATP; 2 acetyl CoA → 4 CO_2 + 4 H_2O + 24 ATP; a total of 38 ATP. The complete oxidation of glucose to CO_2 and water releases 685.5 kilocalories of energy. The ADP system traps 266 (38 x 7) kilocalories of this energy, resulting in a possible storage of 39% (266/685) of the energy in the form of ATP.



continued

56. PATHWAYS OF CARBOHYDRATE METABOLISM

/1/ Adenylic acid and PO_4 required for activity in either direction. /2/ Digestion; glycogen and/or starch are hydrolyzed to glucose in intestinal lumen. /3/ Mg^{++} required for this reaction. /4/ Cori ester. /5/ Robison ester. /6/ Hexokinase reaction assumed to be inhibited by growth hormone plus adrenal cortex hormone; inhibition by these substances is blocked by insulin, thus favoring conversion of glucose to glucose-6-phosphate. /7/ The reaction, glycogen to glucose-6-PO_4 to blood glucose, takes place in liver only; conversion of glucose to glucose-6-PO_4 to glycogen takes place in liver, muscle, and other tissues. /8/ Neuberg ester. /9/ In liver and muscle. /10/ In all tissues. /11/ Hardin-Young ester. /12/ This reaction (to left) causes each step in the conversion to pyruvate to be doubled quantitatively; thus, 1 mole of glucose gives rise to 2 moles of pyruvate. /13/ Hydrogen atoms released. /14/ Hydrogen enters into the reaction. /15/ NAD^+ acts as acceptor of released hydrogen atoms, becoming NADH in oxidative direction of the reaction. NADH gives up hydrogen atoms and becomes NAD^+ in reverse direction. Hydrogen atoms accepted by NAD^+ are passed on in turn to flavoprotein, cytochrome-*c*, cytochrome oxidase, and molecular O_2. If molecular O_2 is not sufficiently available, hydrogen atoms may be passed from NADH to pyruvate-forming lactate. /16/ Inhibited by fluoride. /17/ K^+ also required. /18/ Thiamine pyrophosphate required as coenzyme. /19/ Pyruvate, followed by conversion to lactate when oxygen supply is deficient (*see* Fn. 15), ends glycolysis in animal tissues. If oxygen is available, pyruvate is oxidized via the Krebs cycle. /20/ End of fermentation of plant tissue. /21/ Uridine diphosphate glucose required as coenzyme. /22/ Inhibited by iodoacetate.

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57. PATHWAYS OF AMINO ACID METABOLISM

	Amino Acid	Product of Oxidative Deamination or Transamination	Product of Decarboxylation	Pathways and Products of Metabolism
	(A)	(B)	(C)	(D)
1	L-Alanine	Pyruvic acid		
2	L-Arginine	α-Keto-δ-guanidovaleric acid	Agmatine	Arginine $\rightarrow$ ornithine + urea; arginine $\rightarrow$ citrulline + NH_3; arginine $\rightarrow$ agmatine + CO_2; arginine + glycine $\rightleftharpoons$ guanidoacetic acid + ornithine.
3	L-Asparagine	α-Ketosuccinamic acid		Asparagine $\rightleftharpoons$ aspartic acid + NH_3; asparagine $\rightarrow$ α-ketosuccinamic acid $\rightarrow$ NH_3 + oxalacetic acid.
4	L-Aspartic acid	Oxalacetic acid	α-Alanine, β-alanine	Aspartic acid + carbamylphosphate $\rightarrow$ $PO_4^{\equiv}$ + carbamylaspartic acid $\rightarrow$ pyrimidines; aspartic acid $\rightleftharpoons$ fumaric acid + NH_3; aspartic acid $\rightleftharpoons$ homoserine $\begin{cases} \nearrow \text{threonine} \rightarrow \text{isoleucine} \\ \searrow \text{methionine} \end{cases}$
5	L-Citrulline	α-Keto-δ-carbamidovaleric acid		Citrulline + aspartic acid + ATP $\rightarrow$ AMP + PP + arginosuccinic acid $\rightleftharpoons$ arginine + fumaric acid; citrulline + $PO_4^{\equiv}$ $\rightleftharpoons$ ornithine + carhamylphosphate; citrulline $\rightarrow$ carbamylphosphate + ADP $\rightleftharpoons$ CO_2 + NH_3 + ATP.
6	L-Cysteine & L-cystine	β-Mercaptopyruvic acid		Cysteine $\rightarrow$ β-mercaptopyruvic acid $\rightarrow$ pyruvic acid + S; cysteine $\rightarrow$ H_2S + NH_3 + pyruvic acid; cysteine $\rightarrow$ cysteine sulfinic acid $\rightarrow$ (i) cysteic acid $\rightarrow$ taurine, (ii) hypotaurine, or (iii) via transamination $\rightarrow$ β-sulfinylpyruvate $\rightarrow$ pyruvate + SO_3. (2 cysteine $\rightleftharpoons$ cystine)
7	L-Glutamic acid	α-Ketoglutaric acid	γ-Aminobutyric acid	Glutamic acid $\rightarrow$ γ-aminobutyric acid + CO_2. *See also* ornithine, proline, histidine, glutamine.
8	L-Glutamine	α-Ketoglutaramic acid		Glutamine $\rightleftharpoons$ glutamic acid + NH_3; glutamine $\rightarrow$ α-ketoglutaramic acid $\rightarrow$ NH_3 + α-ketoglutaric acid.

continued

57. PATHWAYS OF AMINO ACID METABOLISM

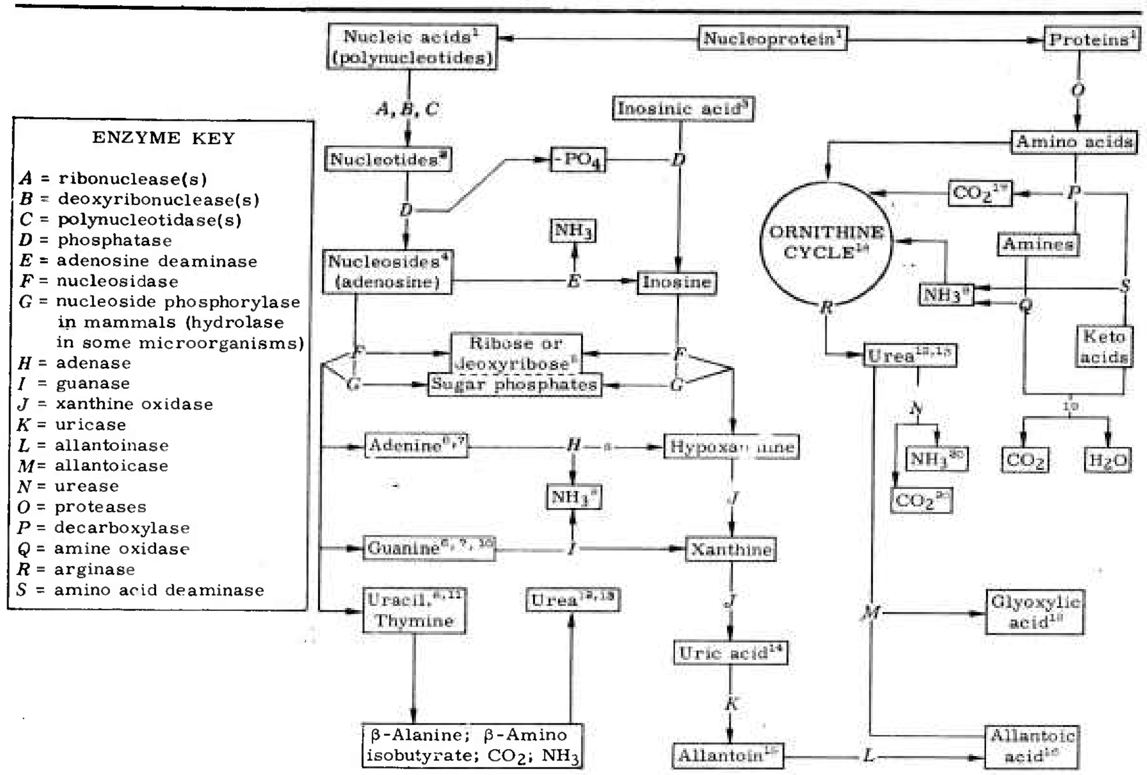
	Amino Acid	Product of Oxidative Deamination or Transamination	Product of Decarboxylation	Pathways and Products of Metabolism
	(A)	(B)	(C)	(D)
9	Glycine	Glyoxylic acid		Glycine + N^{5-10}-methenyl-tetrahydrofolate ⇄ serine + tetrahydrofolate; glycine → glyoxylic acid → formate + CO_2; glycine + succinyl-CoA → δ-aminolevulinate → porphyrins; glycine + 5'-phospho-β-D-ribosamine → purines.
10	L-Histidine	β-Imidazolepyruvic acid	Histamine	Histidine → urocanic acid → glutamic acid + NH_3 + formate; histidine → carnosine; histidine → anserine; histidine → histamine → imidazoleacetic acid → NH_3 + formylaspartic acid.
11	L-Hydroxyproline	α-Keto-γ-hydroxy-δ-aminovaleric acid		Hydroxyproline → Δ^1-proline-4-hydroxy-2-carboxylate → pyrolle-2-carboxylate; hydroxyproline → glutamate.
12	L-Isoleucine	d-α-Keto-β-methylvaleric acid		Isoleucine → α-keto-β-methylvaleric acid → CO_2 + α-methylbutyryl-CoA ⇄ tiglyl-CoA ⇄ α-methyl-β-hydroxybutyryl-CoA ⇄ α-methyl acetoacetyl-CoA ⇄ acetyl-CoA + propionyl-CoA.
13	L-Leucine	α-Ketoisocaproic acid		Leucine → α-ketoisocaproic acid → CO_2 + isovaleryl-CoA ⇄ senecioyl-CoA + CO_2 ⇄ β-methylglutaconyl-CoA ⇄ β-hydroxy-β-methyl glutaryl-CoA ⇄ acetoacetic acid + acetyl-CoA.
14	L-Lysine	α-Keto-ε-aminocaproic acid	Cadaverine	Lysine → α-keto-ε-aminocaproic acid → Δ^1-piperidine-2-carboxylic acid → pipecolic acid → Δ^6-piperidine-2-carboxylic acid → α-aminoadipic-ε-semialdehyde → L-α-aminoadipic acid → α-ketoadipic acid → glutamic acid → α-ketoglutaric acid → L-glutamic acid.
15	L-Methionine	α-Keto-γ-methiolbutyric acid		Methionine → labile CH_3 + homocysteine → (i) homocysteic acid, (ii) H_2S + NH_3 + α-ketobutyric acid, or (iii) serine → cystathionine → cysteine + NH_3 → α-ketobutyric acid.
16	L-Ornithine	Glutamic-γ-semialdehyde, or α-keto-δ-aminovaleric acid	Putrescine	Ornithine ⇄ proline; ornithine ⇄ glutamic acid; ornithine + carbamylphosphate → citrulline. *See also* citrulline.
17	L-Phenylalanine	Phenylpyruvic acid	Phenylethylamine	Phenylalanine → tyrosine; phenylalanine → phenylpyruvic acid → phenylacetic and phenyllactic acids.
18	L-Proline	Glutamic-γ-semialdehyde, or α-keto-δ-aminovaleric acid		Proline ⇄ ornithine; proline ⇄ glutamic acid; proline → hydroxyproline.
19	L-Serine	β-Hydroxypyruvic acid	Ethanolamine	Serine → NH_3 + H_2O + pyruvic acid; serine + indole-3-glycerol phosphate ⇄ tryptophan. *See also* glycine.
20	L-Threonine	d-α-Keto-β-hydroxybutyric acid		Threonine → NH_3 + H_2O + α-ketobutyric acid; threonine → glycine + acetaldehyde; threonine → α-keto-β-hydroxybutyric acid; threonine → aminoacetone. *See also* aspartic acid.
21	L-Tryptophan	β-Indolepyruvic acid	Tryptamine	Tryptophan → formylkynurenine → formate + kynurenine → (i) kynurenic acid, (ii) anthranilic acid + alanine, or (iii) 3-hydroxykynurenine → 3-hydroxyanthranilic acid → 2-acroleyl-3-aminofumaric acid → quinolinic acid → nicotinic acid ribonucleotide; tryptophan → 5-hydroxytryptophan → 5-hydroxytryptamine → 5-hydroxyindoleacetic acid.
22	L-Tyrosine	p-Hydroxyphenylpyruvic acid	Tyramine	Tyrosine → p-hydroxyphenylpyruvic acid → CO_2 + homogentisic acid + maleylacetoacetic acid → fumarylacetoacetic acid → fumaric acid + acetoacetic acid.
23	L-Valine	α-Ketoisovaleric acid		Valine → α-ketoisovaleric acid → CO_2 + isobutyryl-CoA ⇄ methacrylyl-CoA ⇄ β-hydroxybutyryl-CoA ⇄ β-hydroxyisobutyric acid ⇄ methylmalonic acid semialdehyde ⇄ β-aminoisobutyric acid.

Contributors: (a) Meister, Alton, (b) Sallach, H. J., (c) Elwyn, David H., (d) Richert, Dan A., (e) Turner, Robert A.

References: [1] McElroy, W. D., and B. Glass, ed. 1955. Amino acid metabolism. Johns Hopkins Press, Baltimore. [2] Meister, A. 1953. In G. H. Bourne and G. W. Kidder, ed. Biochemistry and physiology of nutrition. Academic Press, New York. v. 1, p. 187. [3] Meister, A. 1964. Biochemistry of the amino acids. Ed. 2. Academic Press, New York. [4] West, E. S., and W. R. Todd. 1961. Textbook of biochemistry. Ed. 3. Macmillan, New York.

58. PATHWAYS OF NUCLEOPROTEIN CATABOLISM

See Table 59 for detailed pathways of purine and pyrimidine nucleotide catabolism.



/1/ Catabolism of nucleoprotein, nucleic acid, and protein may take place in the alimentary canal or in the tissues. /2/ Little intestinal absorption. /3/ In the biosynthesis of nucleotides, inosinic acid is the precursor of adenylic and guanylic acids; in uricotelic species, a portion is a direct precursor of uric acid. /4/ Absorbed from the intestine. Purine nucleosides are split into purines and pentoses by purine nucleosidase present in tissues. /5/ D-Ribose and D-2-deoxyribose are the sugars typical of the two types of nucleic acids. /6/ Mammals do not require but can synthesize exogenous purines or pyrimidines from products of protein metabolism. /7/ Adenine and guanine are the major purines occurring in nucleic acids. /8/ The route adenine → hypoxanthine is of no importance in animals. Adenase is not found to any extent in mammals. /9/ NH_3, as in the case of CO_2, is also used to synthesize many tissue constituents; hence, it may enter into metabolic processes, be built into amino acids, incorporated into urea and excreted, or excreted as NH_3 across the kidney tubule. /10/ Excreted by pig and spider. /11/ Cytosine is converted to uracil at the nucleotide stage. Free cytosine is excreted unchanged. /12/ Excreted by most fishes, amphibians, and freshwater lamellibranchs. /13/ Excreted by mammals as the end product of amino acid metabolism. Excreted by some animals as the end product of purine and pyrimidine metabolism. /14/ Excreted by primates, some reptiles, and some insects as the end product of purine catabolism. Excreted by birds as the end product of protein, purine, and pyrimidine catabolism; no urea formation by birds. /15/ Excreted by most mammals, gastropods, and some insects. /16/ Excreted by some teleost fishes. /17/ May enter into metabolic processes, into the ornithine cycle and be incorporated into and excreted as urea, or be excreted as CO_2. /18/ Urea formation in mammalian liver occurs via the ornithine cycle (Krebs-Henseleit cycle): ornithine → citrulline → arginine succinate → arginine → ornithine. CO_2 and NH_3 enter the cycle via carbamyl glutamic acid at ornithine; NH_3 enters the cycle via aspartic acid at citrulline. Arginine succinate is split to arginine and fumaric acid; arginine is then converted to ornithine with the release of urea. /19/ Via Krebs cycle. In the course of amino acid metabolism, prior to entry into the Krebs cycle, sulfur-containing amino acids lose their sulfur--usually in the form of SO_4. /20/ Crustacea, gephyrean worms, and marine lamellibranchs do not excrete urea but break it down to, and excrete it as, CO_2 and NH_3.

Contributors: (a) Brown, George B., (b) Elwyn, David H., (c) Richert, Dan A., (d) Bishop, David W.

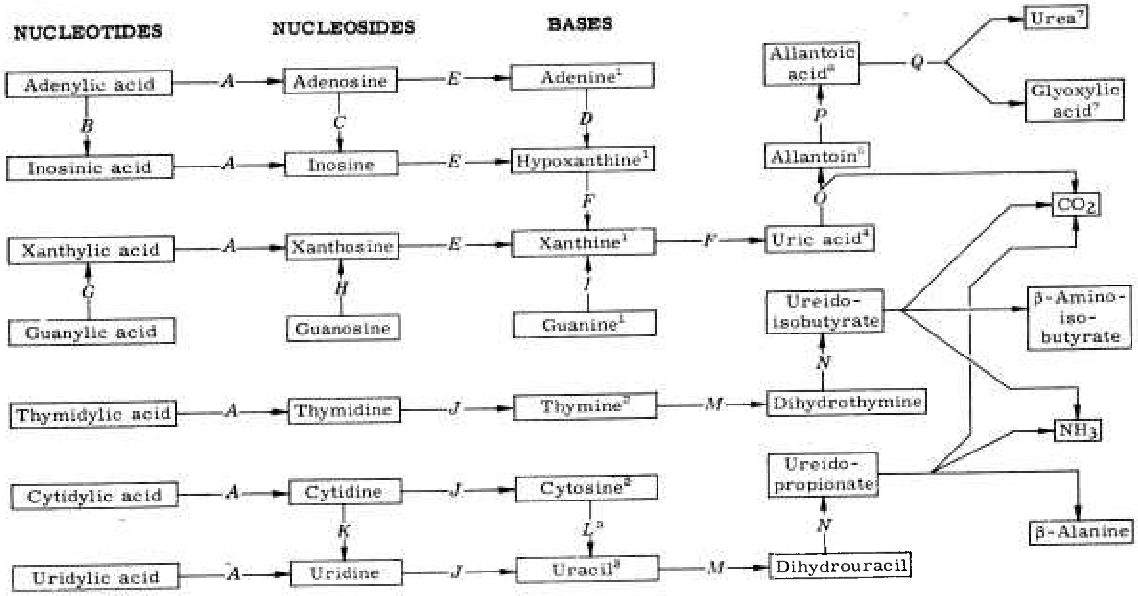
References: [1] Baldwin, E. 1957. Dynamic aspects of biochemistry. Ed. 3. Cambridge Univ. Press, New York. [2] Chargaff, E., and J. N. Davidson, ed. 1955-60. The nucleic acids. Academic Press, New York. [3] Davidson, J. N. 1960. Biochemistry of the nucleic acids. Ed. 4. Methuen, London.

59. PATHWAYS OF PURINE AND PYRIMIDINE CATABOLISM

Nucleoproteins (*see* Table 58) generally are composed of basic proteins (histones or protamines) associated with nucleic acids. The nucleic acids are complex molecules (each composed of many nucleotide units) joined by phosphate sugar linkage. The nucleotides shown below are obtained by enzymic hydrolysis of nucleic acids, although several may be obtained from other sources. Each nucleotide is composed of a purine or pyrimidine base linked to a pentose sugar which, in turn, is linked to phosphate. In catabolism, the phosphate is removed by a nucleotide phosphatase to yield inorganic phosphate and a nucleoside; the nucleoside is cleaved by a nucleoside phosphorylase to give the free base plus ribose-1-phosphate. Also, as a catabolic step, hydrolytic deamination may occur at any level, although it is most frequent at the nucleoside level.

ENZYME KEY

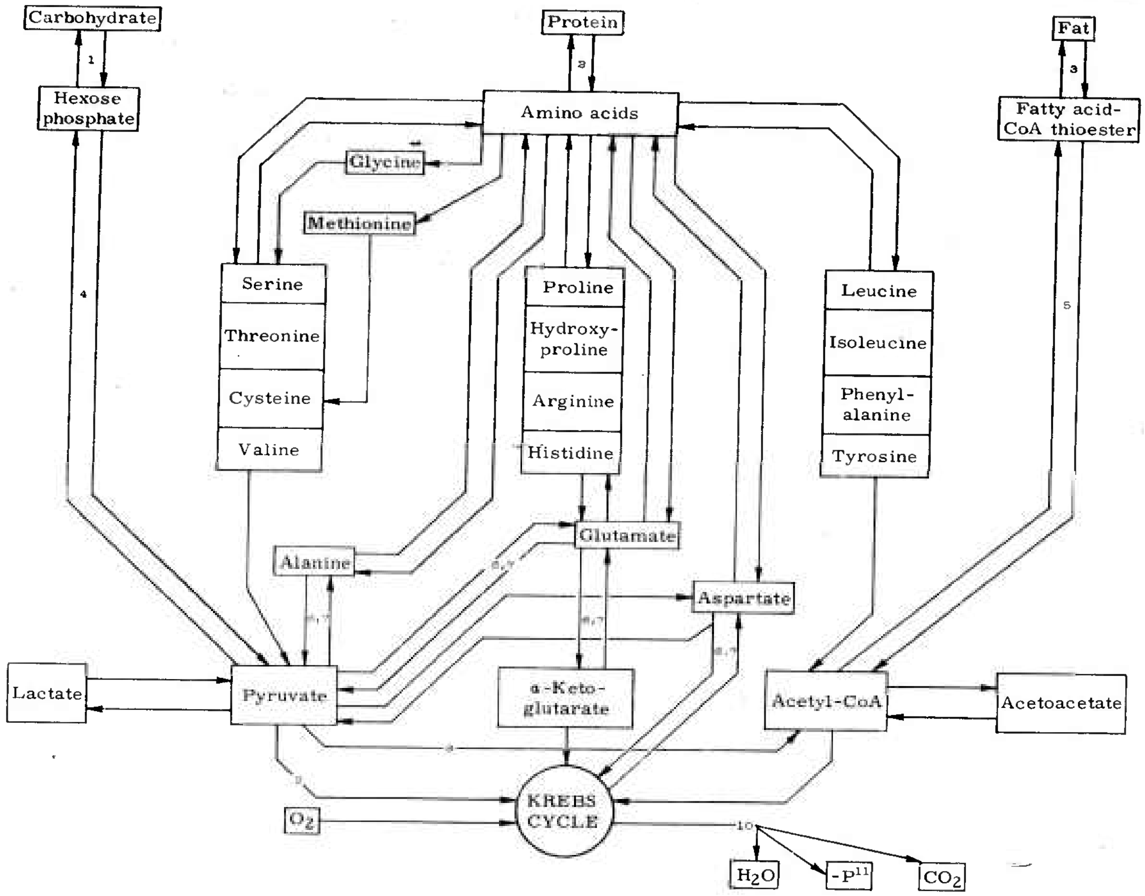
A = phosphatase
B = adenylate deaminase
C = adenosine deaminase
D = adenase
E = nucleoside phosphorylase
F = xanthine oxidase
G = guanylate deaminase
H = guanosine deaminase
I = guanase
J = phosphorylase or hydrolase
K = cytidine deaminase
L = cytosine deaminase
M = dihydropyrimidine dehydrogenase
N = dihydropyrimidine hydrase
O = uricase
P = allantoinase
Q = allantoicase



/1/ Purine. /2/ Pyrimidine. /3/ Demonstrated in yeast and *Escherichia coli*. /4/ End product of primates, birds, terrestrial reptiles, and most insects. /5/ End product of mammals other than primates. /6/ End product of some teleost fishes. /7/ End product of most fishes, amphibians, and freshwater lamellibranchs.

Contributors: (a) Barrett, Harold W., (b) Lansford, Edwin M., Jr., and Shive, William, (c) Zbarsky, S. H.

References: [1] Baldwin, E. 1957. Dynamic aspects of biochemistry. Ed. 3. Cambridge Univ. Press, New York. [2] Cantarow, A., and B. Schepartz. 1962. Biochemistry. Ed. 3. W. B. Saunders, Philadelphia. [3] Chargaff, E., and J. N. Davidson. 1955-60. The nucleic acids. Academic Press, New York. [4] Colowick, S. P., and N. O. Kaplan. 1955. Methods in enzymology. Academic Press, New York. v. 2. [5] Davidson, J. N. 1960. Biochemistry of the nucleic acids. Ed. 4. Methuen, London. [6] West, E. S., and W. R. Todd. 1961. Textbook of biochemistry. Ed. 3. Macmillan, New York. [7] White, A., et al. 1959. Principles of biochemistry. McGraw-Hill, New York.



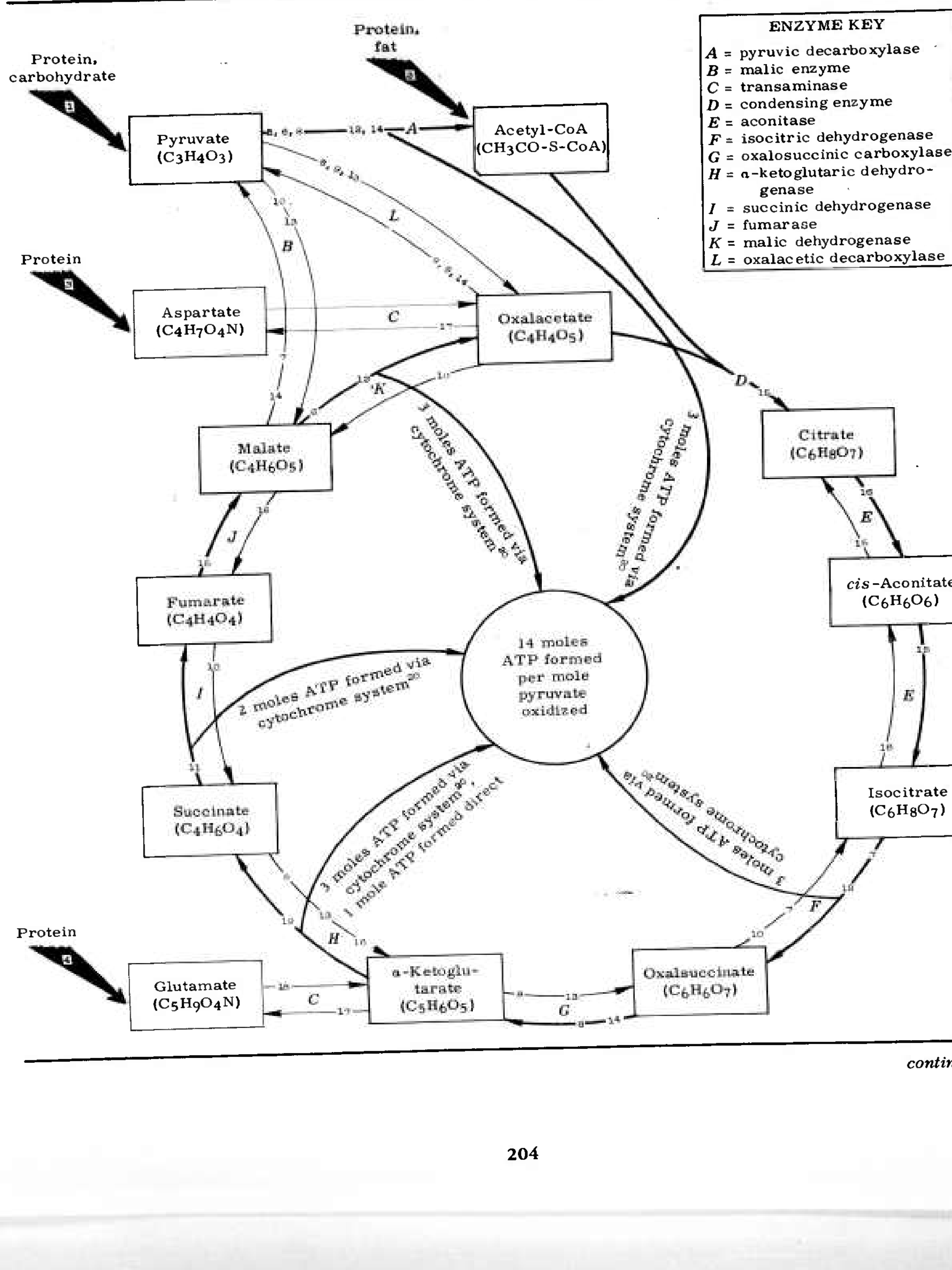
/1/ Phosphorylation of hexose units in stored polysaccharides by phosphorylase and phosphate; phosphorylation of hexoses by hexokinase and ATP. /2/ Proteolysis by proteases in digestive tract or tissues. /3/ Lipase splits fat into fatty acids and glycerol. (Glycerol, via glycerol phosphate and dihydroxyacetone phosphate, enters the glycolytic cycle. Fatty acid then is acted upon by coenzyme A.) /4/ Glycolysis. /5/ β-Oxidation. /6/ Oxidative deamination. /7/ Transamination. /8/ Oxidative decarboxylation. /9/ Carboxylation. /10/ Chain of electron-transmitting enzymes. /11/ High energy phosphorus.

Contributors: (a) Bonner, James F., and Saltman, Paul, (b) Van Bruggen, John T., (c) Elwyn, David H., (d) Welt, Isaac D.

References: [1] Baldwin, E. 1957. Dynamic aspects of biochemistry. Ed. 3. Cambridge Univ. Press, New York. [2] Fruton, J. S., and S. Simmonds. 1958. General biochemistry. Ed. 2. J. Wiley, New York. [3] Greenberg, D. M. 1960-61. Metabolic pathways. Academic Press, New York. [4] West, E. S., and W. R. Todd. 1961. Textbook of biochemistry. Ed. 3. Macmillan, New York. [5] White, A., et al. 1959. Principles of biochemistry. Ed. 2. McGraw-Hill, New York.

61. KREBS CYCLE

The Krebs cycle (tricarboxylic acid cycle) is a major pathway for the final aerobic oxidation of carbohydrates, fats, and proteins, which are channeled into the cycle via their two key metabolites, pyruvate and acetyl-CoA (active acetate). Each "revolution" of the cycle oxidizes acetate to CO_2 and H_2O. One mole (59 g) of acetate thus oxidized releases approximately 200 kilocalories of energy. A portion of the released energy (approximately 144 kilocalories) enters the phosphate pool as ATP. Twelve moles of ATP are formed from ADP and PO_4 (by energizing PO_4 to $\sim PO_4$). The remainder of the released energy appears as heat. Oxidation of 1 mole (87 g) of pyruvate, via acetyl-CoA, contributes a total of 14 moles of ATP to the energy pool. Heavy lines indicate main sequence of reactions.



continued

61. KREBS CYCLE

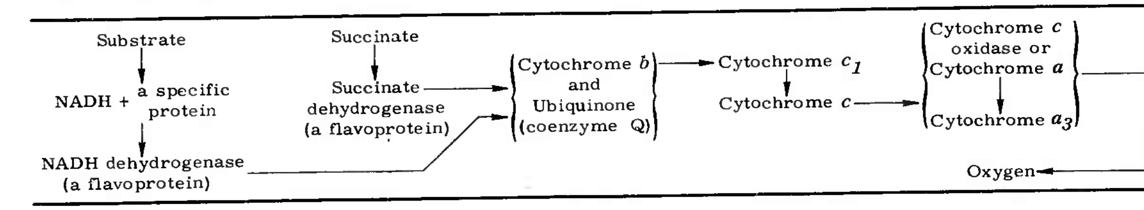
/1/ Glucogenic amino acid precursors for pyruvate are alanine, glycine, serine, threonine, methionine, cysteine, valine. /2/ Ketogenic amino acid precursors for acetyl-CoA are leucine, isoleucine, phenylalanine, tyrosine. /3/ Aspartic acid occurs as a component of protein. /4/ Glutamic acid occurs as a component of protein or may be formed from arginine, proline, hydroxyproline, histidine, ornithine. /5/ Coenzyme A (ATP-pantoyl-β-alanyl-thioethanolamine) and α-lipoic acid required. /6/ In the oxidative direction, NAD^+ (nicotinamide adenine dinucleotide) acts as hydrogen acceptor; in the reverse direction, NADH is hydrogen donor. /7/ In the oxidative direction, $NADP^+$ (nicotinamide adenine dinucleotide phosphate) acts as hydrogen acceptor; in the reverse direction, NADPH is hydrogen donor. /8/ Cocarboxylase (thiamine pyrophosphate) required as coenzyme for the carboxylase *(A)*; also Mg^{++} or Mn^{++} required as activator for the enzyme. /9/ Biotin required as coenzyme for decarboxylation. /10/ Two moles of hydrogen enter into the reaction. /11/ Two moles of hydrogen released and their electrons transferred to cytochrome. /12/ Hydrogen atoms transferred to NAD^+ (or, in the case of isocitrate → oxalsuccinate, to $NADP^+$) and pass in turn to flavoprotein, cytochrome-*c*, cytochrome oxidase, and finally to combination with molecular oxygen. For each mole of hydrogen thus passed and finally oxidized, 1.5 moles of ATP are formed by the addition of energized phosphate ($-PO_4$) to ADP. /13/ CO_2 enters into the reaction. /14/ CO_2 released. /15/ H_2O enters into the reaction. /16/ H_2O released. /17/ NH_3 enters into the reaction by transamination. /18/ NH_3 transferred from glutamate by transamination, then enters into Krebs cycle via α-ketoglutarate. /19/ Footnotes 5, 6, 8, 12, 14 apply to this reaction. /20/ For details, *see* Table 62 on the cytochrome system.

Contributors: (a) Bishop, David W., (b) Bonner, James F., (c) Roe, Joseph H., (d) Welt, Isaac D.

References: [1] Artom, C. 1953. Ann. Rev. Biochem. 22:211. [2] Baldwin, E. 1957. Dynamic aspects of biochemistry. Ed. 3. Cambridge Univ. Press, New York. p. 415. [3] Black, K. 1952. Ann. Rev. Biochem. 21:273. [4] Dickens, F. 1951. In J. B. Sumner and K. Myrbäck, ed. The enzymes. Academic Press, New York. v. 2, p. 624. [5] Evans, E. A., Jr. 1944. Ann. Rev. Biochem. 13:187. [6] Frazer, A. C. 1952. Ibid. 21:245. [7] Fruton, J. S., and S. Simmonds. 1958. General biochemistry. Ed. 2. J. Wiley, New York. [8] Greenberg, D. M. 1960-61. Metabolic pathways. Academic Press, New York. [9] Krebs, H. A. 1943. Advan. Enzymol. 3:191. [10] Ochoa, S. 1951. Physiol. Rev. 31:56. [11] Ochoa, S., and J. R. Stern. 1952. Ann. Rev. Biochem. 21:547. [12] Potter, V. R., and C. Heidelberger. 1950. Physiol. Rev. 30:487. [13] Umbreit, W. W. 1952. Metabolic maps. Burgess, Minneapolis. p. 90. [14] West, E. S., and W. R. Todd. 1961. Textbook of biochemistry. Ed. 3. Macmillan, New York. [15] White, A., et al. 1959. Principles of biochemistry. Ed. 2. McGraw-Hill, New York.

62. CYTOCHROME SYSTEM

The cytochromes (iron-containing compounds) in association with certain enzymes comprise the cytochrome system. The system operates as the final pathway by which an intermediate metabolite (substrate), under the influence of its specific dehydrogenase, releases hydrogen to the first member in a series of carriers for ultimate combination with oxygen to form water. Each step in the process involves both oxidation and reduction: the cytochrome system oxidizes the hydrogen of the substrate by removing electrons from it, thereby producing oxidized substrate and hydrogen ions. The system itself is reduced in the process and is finally oxidized by molecular oxygen. For each gram of hydrogen thus passed to NADH and finally oxidized, enough energy is produced to form 1.5 moles of ATP from ADP and PO_4.



Contributor: Wainio, Walter W.

References: [1] Chance, B. 1961. In J. E. Falk, ed. Haematin enzymes. Pergamon Press, Oxford. p. 597. [2] Green, D. E. 1961. Ciba Found. Symp. Quinones Electron Transport, 1960, p. 130. [3] Okunuki, K., et al. 1958. Proc. Intern. Symp. Enzyme Chem., Tokyo-Kyoto, 1957, p. 264. [4] Slater, E. C. 1958. Advan. Enzymol. 20:147. [5] Slater, E. C. 1961. In J. E. Falk, ed. Haematin enzymes. Pergamon Press, Oxford. p. 575. [6] Wainio, W. W. 1953. Rutgers Univ. Bur. Biol. Res. Symp. Some Conjugated Proteins, p. 19. [7] Wainio, W. W. 1961. In J. E. Falk, ed. Haematin enzymes. Pergamon Press, Oxford. p. 281.

63. PROPERTIES OF CYTOCHROMES: ANIMALS AND HIGHER PLANTS

The cytochromes of animals and higher plants are intracellular chromoproteins which are entirely associated with lipoprotein structural elements of cytoplasm. The prosthetic group contains coordinated iron which may undergo alternate oxidation and reduction. **Physical and Chemical Properties** (column C): PG = prosthetic group; MW = molecular weight; E_0' = oxidation-reduction potential. **Spectral Characteristics** (columns D and E): λ maximum in mμ = wave length of maximum absorption; figures in parentheses are $E^{mM}_{1\,cm}$, i.e., extinction coefficients of millimolar solutions of 1-cm thickness.

	Source of Pigments	Cytochrome	Physical and Chemical Properties	Spectral Characteristics λ maximum in mμ		Remarks	Reference
				Reduced	Oxidized		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Animals						
1	Mitochondria[1]	*a*	PG = hematin-*a*; E_0' = 0.29 volts	603 452	590-600 418-420	Closely associated with cytochrome-a_3	B,3,19,25,35; C,3,25;D,19; E,35;F,29
2		a_3		604 448	590-600 418-420	Carbon monoxide-a_3 complex, when reduced, has absorption bands at 590-593 mμ and at 432 mμ	B,D,19;E,35; F,6,19
3		*b*	PG = protohematin; E_0' = -0.04 volts	564((20.8) 530 430	 416	May not be on direct electron transfer path	B,D,16,31;C, 3,16,31;E,16; F,29
4		*c*	MW = 12,200; PG = hematin-*c*; Fe = 0.45%; heat stable at neutral pH; isoelectric point = pH 10.5-10.8; E_0' = 0.255 volts	550 (27.8) 520 415 316	 530 408 355	Data refer to pigment purified from horse heart. Fe content may be increased by enrichment with iron-containing impurities.	B,11,13,17,18, 22,34;C,13, 17,18,34;D, E,11,22;F, 11,13,22,34
5		c_1	PG = hematin-*c*	553-554 522-524 416-418	 410	Identical with cytochrome-*e*	B,D,20,30;C, E,30;F,20,21
6	Endoplasmic reticulum[2]	b_5	MW = 16,900; PG = protohematin; non-mitochondrial oxidation of NADH and NADPH; E_0' = 0.12 volts	556 (25.6) 526 423 320-340	500-580 413 355-370	Identical with cytochrome-*m*. Separate flavoproteins catalyze the reactions of NADH and of NADPH with cytochrome-b_5 in animal tissues.	B,D,E,33;C,2, 33;F,2,32
7	Intracellular[3]	*h*	MW = 18,500; PG = modified protohematin; Fe = 0.33%; heat stable at neutral pH; isoelectric point = <pH 4.3; E_0' = 0.20 volts	556 (22.7) 526.5 422	562 536 408	Occurs in land snails and other invertebrates. Helicorubin is probably a degraded form of cytochrome-*h*.	B,C,F,23,24; D,E,23,29
	Higher Plants						
8	Mitochondria[4]	*a*	As found in animal mitochondria. Presence indicated by spectroscopic and spectrophotometric observations.				5,12,27,28
9		a_3	As found in animal mitochondria. Presence indicated by spectroscopic and spectrophotometric observations.			Role in electron transport inferred from cyanide inhibition of respiration, and from shift in spectrum observed with carbon monoxide	B-E,5,12,27, 28;F,12,26, 28
10		*b*	As found in animal mitochondria. Presence indicated by spectroscopic and spectrophotometric observations.				5,12,27,28
11		*c*	As found in animal mitochondria. Presence indicated by spectroscopic and spectrophotometric observations.				5,10,12,27,28
12		c_1	As found in animal mitochondria. Presence indicated by spectroscopic and spectrophotometric observations.			Present in high concentration in wheat roots	B-E,5,10,12, 27,28;F,28
13		b_7	E_0' = -0.03	560 529		Observed in mitochondria from spadix of *Arum maculatum*	B,F,4;C,29;D, 4,29

/1/ From rat liver [7]. /2/ Found in microsomes [2, 32]. /3/ Intracellular localization unknown. /4/ From wheat roots.

continued

63. PROPERTIES OF CYTOCHROMES: ANIMALS AND HIGHER PLANTS

	Source of Pigments[3]	Cyto-chrome	Physical and Chemical Properties	Spectral Characteristics λ maximum in mμ Reduced	Oxidized	Remarks	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Higher Plants						
14	Endoplasmic reticulum[5]	b_3	PG = protohematin; non-mitochondrial oxidation of NADH and NADPH	559 525 425		Observed in microsomes from wheat roots and beet petiole. A pigment with a similar spectrum observed in autolysates of green leaves.	B,D,27,28;C,27;F,15,28
15	Chloroplasts[6]	b_6	PG = protohematin; E_0' = -0.06 volts	563		Distinguished from cytochrome-*b* by greater stability to organic solvents	B,F,14;C,29;D,14,29
16		*f*	MW = 110,000; PG = hematin-*c*; heat labile; E_0' = 0.365 volts	555 526 421 330	 410 350	Isolated from parsley. Localization in chloroplasts observed in etiolated leaves.	B,E,9;C,D,9,29;F,8,9

/5/ Found in microsomes [27]. /6/ Cytochrome-b_6 and cytochrome-*f* probably are components of a system for oxidation of reduced lipoic acid formed during photosynthesis. The energy from this oxidation is used for generation of ATP from ADP and inorganic phosphate. [1]

Contributors: Morton, R. K., and Armstrong, J. M.

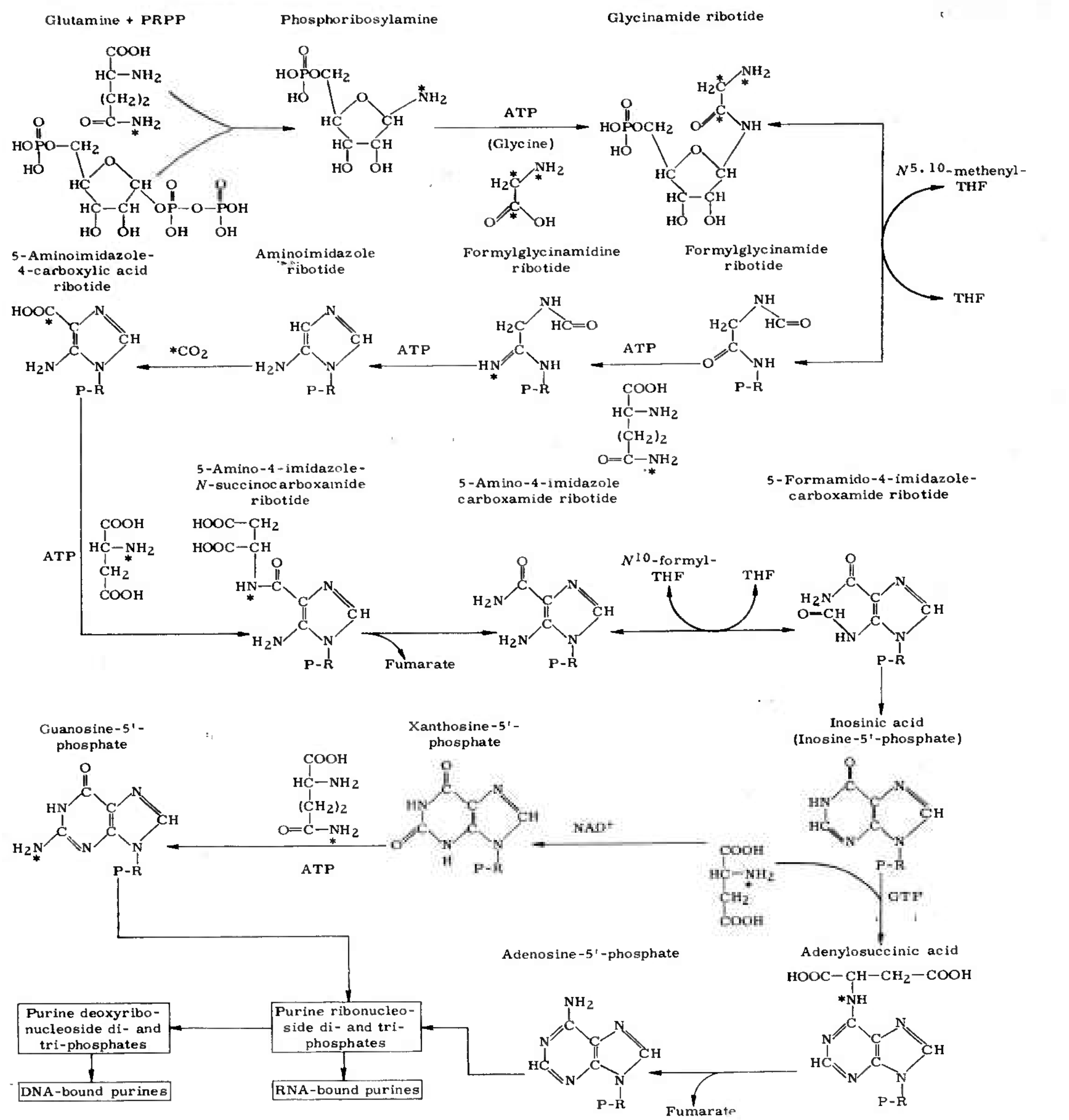
References: [1] Arnon, D. I. 1955. Science 122:9. [2] Bailie, M., and R. K. Morton. 1955. Nature 176:111. [3] Ball, E. 1938. Biochem. Z. 295:262. [4] Bendall, D. S., and R. Hill. 1956. New Phytologist 55:206. [5] Bhagvat, K., and R. Hill. 1951. Ibid. 50:112. [6] Chance, B. 1953. J. Biol. Chem. 202:397. [7] Chance, B., and G. R. Williams. 1955. Ibid. 217:395. [8] Davenport, H. E. 1952. Nature 170:1112. [9] Davenport, H. E., and R. Hill. 1952. Proc. Roy. Soc. (London), B, 139:327. [10] Goddard, D. R. 1944. Am. J. Botany 31:270. [11] Hagihara, B., et al. 1956. Nature 178:631. [12] Hartree, E. F. 1957. Advan. Enzymol. 18:1. [13] Henderson, R. W., and W. A. Rawlinson. 1956. Biochem. J. 62:21. [14] Hill, R. 1954. Nature 174:501. [15] Hill, R., and R. Scarisbrick. 1951. New Phytologist 50:98. [16] Hübscher, G., M. Kiese, and R. Nicholas. 1954. Biochem. Z. 325:223. [17] Keilin, D. 1929. Proc. Roy. Soc. (London), B, 104:206. [18] Keilin, D., and E. F. Hartree. 1937. Ibid., B, 122:298. [19] Keilin, D., and E. F. Hartree. 1939. Ibid., B, 127:167. [20] Keilin, D., and E. F. Hartree. 1949. Nature 164:254. [21] Keilin, D., and E. F. Hartree. 1955. Ibid. 176:200. [22] Keilin, D., and E. C. Slater. 1953. Brit. Med. Bull. 9:89. [23] Keilin, J. 1956. Biochem. J. 64:663. [24] Keilin, J. 1957. Nature 180:427. [25] Lemberg, R. 1953. Ibid. 172:619. [26] Lundegårdh, H. 1952. Ibid. 169:1088. [27] Martin, E. M., and R. K. Morton. 1955. Ibid. 176:113. [28] Martin, E. M., and R. K. Morton. 1957. Biochem. J. 65:404. [29] Neilands, J. B. 1958. Ann. Rev. Biochem. 27:455. [30] Okunuki, K., and E. Yakashiji. 1941. Proc. Imp. Acad. (Tokyo) 17:263. [31] Sekuzu, I., and K. Okunuki. 1956. J. Biochem. (Tokyo) 43:107. [32] Strittmatter, P., and E. Ball. 1954. J. Cellular Comp. Physiol. 43:57. [33] Strittmatter, P., and S. F. Velick. 1956. J. Biol. Chem. 221:253. [34] Tint, H., and W. Reiss. 1950. Ibid. 182:385. [35] Wainio, W. W., and S. J. Cooperstein. 1956. Advan. Enzymol. 17:347.

64. PATHWAYS OF BIOSYNTHESIS: PURINES

* = isotopically labeled atom incorporated into next product.

ENZYME KEY

ATP = adenosine triphosphate
NAD+ = nicotinamide adenine dinucleotide (oxidized form)
P-R = ribosyl-5'-phosphate
GTP = guanosine triphosphate
PRPP = phosphoribosylpyrophosphate
THF = tetrahydrofolic acid coenzyme

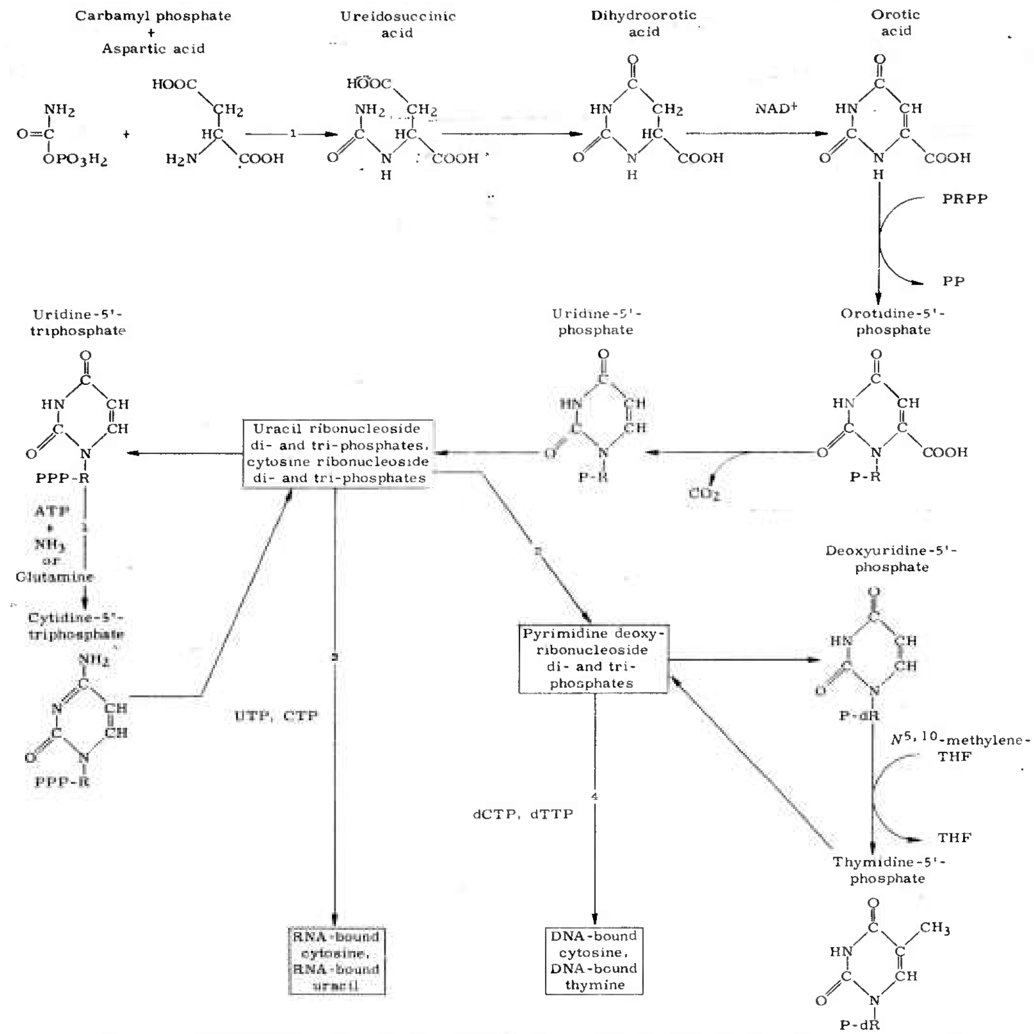


Contributors: Lansford, Edwin M., Jr., and Shive, William

References: [1] Buchanan, J. M., et al. 1959. J. Cellular Comp. Physiol. 54:139. [2] Hartman, S. C., and J. M. Buchanan. 1959. Ann. Rev. Biochem. 28:365. [3] White, A., et al. 1959. Principles of biochemistry. Ed. 2. McGraw-Hill, New York. p. 582.

ENZYME KEY

ATP = adenosine triphosphate	PP = inorganic pyrophosphate
CTP = cytidine triphosphate	PRPP = phosphoribosylpyrophosphate
dCTP = deoxycytidine triphosphate	P-R = 5'-ribosylphosphate
UTP = uridine triphosphate	PPP-R = 5'-ribosyltriphosphate
dTTP = deoxythymidine triphosphate	P-dR = 5'-deoxyribosulphosphate
NAD^+ = nicotinamide adenine dinucleotide	THF = tetrahydrofolate coenzyme



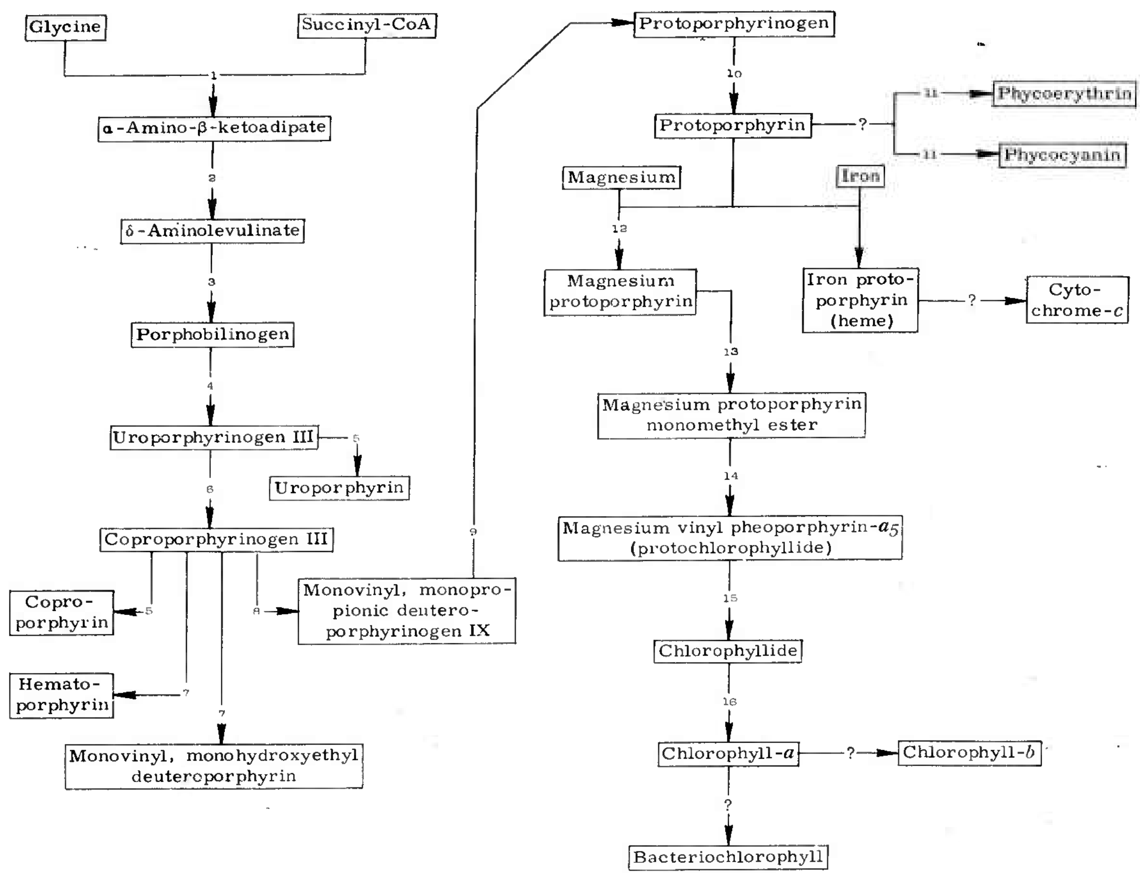
/1/ The mechanism for this reaction varies slightly with the enzyme source (animal or microbial). /2/ One or more enzymic reactions not yet fully elucidated. /3/ Reaction catalyzed by RNA polymerase. /4/ Reaction catalyzed by DNA polymerase.

Contributors: Lansford, Edwin M., Jr., and Shive, William

References: [1] Buchanan, J. M., et al. 1959. J. Cellular Comp. Physiol. 54:139. [2] Hartman, S. C., and J. M. Buchanan. 1959. Ann. Rev. Biochem. 28:365. [3] White, A., et al. 1959. Principles of biochemistry. Ed. 2. McGraw-Hill, New York. p. 582.

66. PATHWAYS OF BIOSYNTHESIS: CHLOROPHYLL

Diagram summarizes present knowledge of the pathways leading to synthesis of chlorophyll in plants.



/1/ Condensation of glycine with succinyl-CoA produces α-amino-β-ketoadipate. /2/ Decarboxylates to δ-aminolevulinate. /3/ Two molecules of δ-aminolevulinate are condensed by a dehydrase enzyme, forming the pyrrole amine, porphobilinogen. /4/ Four molecules of porphobilinogen are condensed, forming a reduced porphyrin, uroporphyrinogen III. /5/ Autoxidation products found in congenital porphyria. /6/ Decarboxylation of uroporphyrinogen III to coproporphyrinogen III. /7/ Side products found in a *Chlorella* mutant. /8/ Oxidation of one propionic side chain to vinyl. /9/ Oxidation of one propionic side chain to vinyl, producing protoporphyrinogen. /10/ Autoxidation to protoporphyrin. /11/ Open-chain bile pigment chemically bound to protein. /12/ Magnesium protoporphyrin found in a *Chlorella* mutant. /13/ Found in a *Chlorella* mutant and etiolated barley. /14/ Three or four steps postulated, including reduction of a vinyl side chain to ethyl, oxidation of a propionic acid group and cyclization to a cyclopentanone ring. Found in a *Chlorella* mutant. /15/ Addition of two hydrogen atoms on pyrrole ring D of protochlorophyllide. /16/ Esterification of a propionic acid group with phytol, a C-20 alcohol.

Contributor: Granick, S.

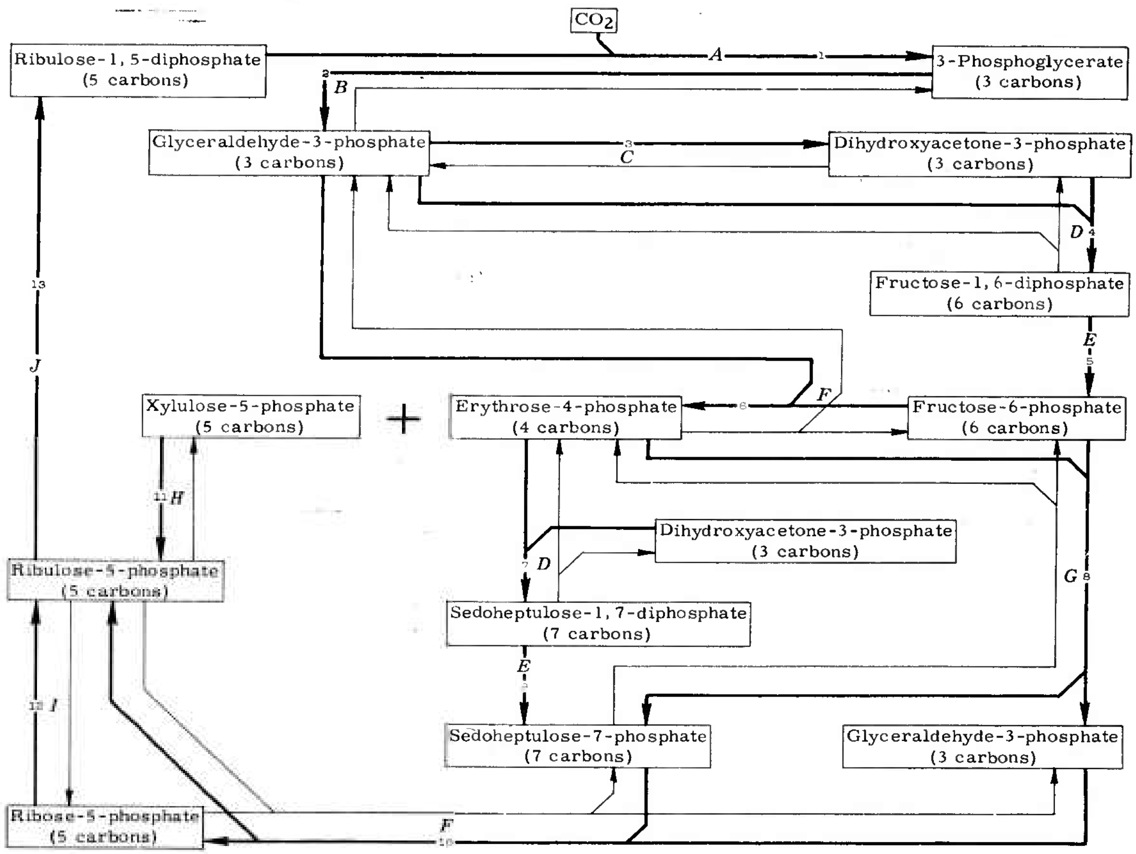
References: [1] Granick, S. 1951. Ann. Rev. Plant Physiol. 2:115. [2] Shemin, D. 1955. Ciba Found. Symp. Porphyrin Biosyn. Metab., p. 4.

67. PATHWAYS OF PHOTOSYNTHESIS: CARBON DIOXIDE REDUCTION CYCLE

According to current evidence, photosynthetic carbon dioxide reduction follows the same general pathways in all plants. The first reaction results in formation of two molecules of phosphoglycerate from carbon dioxide and ribulose diphosphate. Phosphoglycerate is then reduced via the reverse of glycolysis (indicated by light arrows) to supply hexose phosphates for synthesis of sucrose and polysaccharides. A portion of the intermediate compounds goes through the sequence of reactions shown in the diagram, leading to regeneration of the carbon dioxide acceptor, ribulose diphosphate. It is not known whether one or both of the pathways to sedoheptulose phosphate (step 8 and steps 7 and 9) are important in carbon reduction during photosynthesis. Heavy arrows indicate directions of material transfer during steady state photosynthesis.

ENZYME KEY

A = ribulose diphosphate carboxylase (carboxydismutase)	*D* = aldolase	*H* = phosphoketopentose epimerase
B = triosephosphate dehydrogenase	*E* = phosphatase	*I* = phosphoriboisomerase
C = triosephosphate isomerase	*F* = transketolase	*G* = transaldolase
		J = phosphoribulokinase



/1/ Ribulose diphosphate adds CO_2 at carbon-2 and splits hydrolytically to give two molecules of 3-phosphoglycerate. /2/ The carboxyl group is reduced to an aldehyde group with the aid of ATP and NADPH. /3/ Isomerization involves transfer of two hydrogen atoms from carbon-2 to carbon-1. /4/ Aldol condensation of carbon-1 of glyceraldehyde-3-P with carbon-1 of dihydroxyacetone-3-P. /5/ Removal of the phosphate ester group from carbon-1 by hydrolysis. /6/ Two hydrogen atoms plus the glycolyl group (carbon-1, 2) of fructose transferred to glyceraldehyde-P to form xylulose-5-P, leaving erythrose-P. /7/ Aldol condensation of carbon-1 of erythrose-4-P with carbon-1 of dihydroxyacetone-3-P obtained from step 3. /8/ Transfer of triose group (carbon-1, 2, 3) from fructose-6-P to carbon-1 of erythrose-4-P, leaving glyceraldehyde-3-P from carbon-4, 5, 6 of the fructose-6-P. /9/ Hydrolysis of the phosphate ester group on carbon-1 to give inorganic phosphate. /10/ Transfer of the glycolyl group (carbon-1, 2) of sedoheptulose-7-P to carbon-1 of glyceraldehyde-3-P to give ribulose-5-P, leaving ribose-5-P. /11/ Epimerization of carbon-3 of ketopentose. Xylulose-5-P isomerizes to ribulose-5-P with phosphoketopentose epimerase. /12/ Isomerization of aldose to ketose by the transfer of two hydrogen atoms. /13/ Phosphorylation of carbon-1 by reaction with ATP.

continued

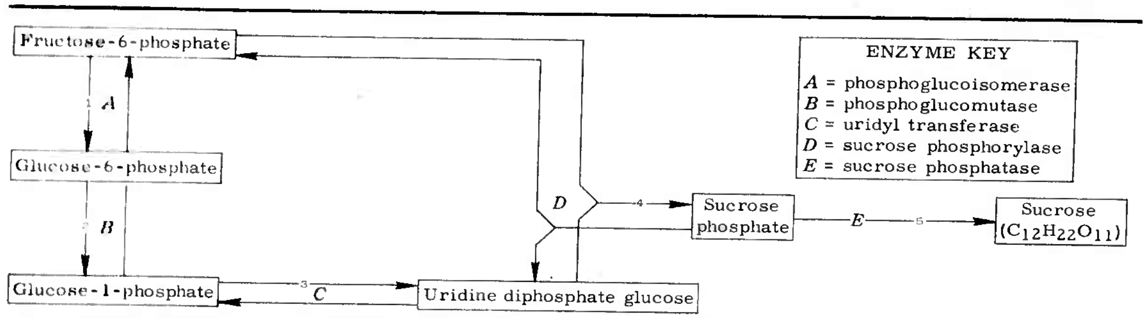
67. PATHWAYS OF PHOTOSYNTHESIS: CARBON DIOXIDE REDUCTION CYCLE

Contributors: (a) Benson, Andrew A., (b) Calvin, Melvin, and Bassham, James A.

References: [1] Bassham, J. A., and M. Calvin. 1957. The path of carbon in photosynthesis. Prentice-Hall, Englewood Cliffs, N. J. [2] Calvin, M., and J. A. Bassham. 1962. The photosynthesis of carbon compounds. W. A. Benjamin, New York.

68. PATHWAYS OF SUCROSE SYNTHESIS: INTERMEDIATES

Sucrose, common to all green plants, is the first free sugar formed by a series of steps involving phosphorylated intermediates. Photosynthesis supplies reduced pyridine nucleotides and adenosine triphosphate (ATP). Phosphoglycerate, provided by the photosynthetic carboxylation reaction, is reduced and condensed to form hexose molecules. Energy required to produce sucrose from hexose phosphates comes largely from high-energy uridine triphosphate (UTP) which becomes uridine diphosphate glucose (UDP-glucose) for condensation with fructose phosphate.



/1/ Hydrogen atom on carbon-1 shifts to carbon-2, forming the epimer, glucose-6-phosphate; furanose ring structure is changed to pyranose. /2/ Phosphate group on carbon-6 is transferred to carbon-1 through the required coenzyme intermediate, glucose-1, 6-diphosphate; Mg^{++} is required. /3/ UTP reacts with glucose-1-phosphate to form pyrophosphate and UDP-glucose. /4/ Fructose-6-phosphate and UDP-glucose react to give UDP and an unstable sucrose phosphate. /5/ Hydrolysis occurs to give free sucrose and orthophosphate.

Contributors: (a) Benson, Andrew A., (b) Calvin, Melvin, and Bassham, James A.

References: [1] Bassham, J. A., and M. Calvin. 1957. The path of carbon in photosynthesis. Prentice-Hall, Englewood Cliffs, N. J. [2] Calvin, M., and J. A. Bassham. 1962. The photosynthesis of carbon compounds. W. A. Benjamin, New York.

69. PHOTOSYNTHESIS: APPARENT RATES

Photosynthesis is complicated by such factors as light intensity, temperature, CO_2 concentration, and certain internal conditions of the plant.

Part I. MAXIMUM RATES: NATURAL CONDITIONS, VARIOUS LOCALES

Values are mg CO_2 per 100 sq cm per hour, unless otherwise indicated, and are uncorrected for respiration. Determinations were made chiefly in sunlight; those made in the shade are enclosed in parentheses.

	Species	Common Name	Location	Temp. °C	CO_2 Fixation	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
	Lichenes					
1	*Lasallia papulosa*	Rock tripe	Southern Sweden	28	2.0	28
2	*Lobaria pulmonaria*	Lungwort	Southern Sweden	27	(2.2)	28

continued

69. PHOTOSYNTHESIS: APPARENT RATES

Part I. MAXIMUM RATES: NATURAL CONDITIONS, VARIOUS LOCALES

	Species	Common Name	Location	Temp. °C	CO_2 Fixation	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
	Algae					
3	*Fucus serratus*	Rockweed	Helgoland	17	4.50	15
4	*Laminaria saccharina*	Kelp	Helgoland	20	1.75	15
5	*Porphyra laciniata*	Porphyra	Helgoland	17	2.09	15
6			Naples	23	1.64	15
7	*Ulva lactuca*	Sea lettuce	Naples	21-23	1.62	15
	Pteridophyta					
8	*Dryopteris spinulosa*	Toothed wood fern	Southern Sweden	....	3.96	14
9	*Polypodium vulgare*	Common polypody	Southern Sweden	....	(5.60)	14
	Gymnospermae					
10	*Picea abies*	Norway spruce	Southern Sweden	....	1.5 (2.1)[1]	27
11			Germany	-2 to +3	0.096[2]	31
12			Germany	6-12	0.29[2]	31
13	*Pinus taeda*	Loblolly pine	North Carolina	26	14.3	19
14			Massachusetts	....	(2.51)	18
	Angiospermae					
15	*Acer platanoides*	Norway maple	Stockholm	18-20	1.22[3]	27
16	*A. tschonoski*	Tschonoski maple	Japan	....	(4.1)	13
17	*Allium victorialis*	Long-root onion	Leningrad	....	3.66	8
18	*Avena* sp.	Oat	Denmark	20	13.0	4
19	*Beta vulgaris*	Beet	Sweden	....	20.1	20,21
20	*Betula pendula*	European white birch	Denmark	20	6.4	5,6
21	*Catalpa bignonioides*	Southern catalpa	England	....	4.7	7
22	*Chrysanthemum alpinum*	Alpine chrysanthemum	Alps	14	(84.1)	12
23	*Citrus limon*	Lemon	Southern USSR	25-28	15-26	9
24	*Cucumis sativus*	Cucumber	USSR	25	10.91-11.98	24,25
25	*Cucurbita pepo*	Pumpkin	Germany	....	20[3]	26
26	*Fagopyrum esculentum*	Buckwheat	USSR	....	10.5	22
27	*Fagus sylvatica*	European beech	Denmark	20	6.6 (2.4)	3
28	*Fraxinus excelsior*	European ash	Denmark	20	9.8 (4.2)	3
29	*Glycine soja*	Soybean	USSR	25	7.93-8.78	24,25
30	*Gossypium hirsutum*	Upland cotton	USSR	....	7.98	32
31	*Helianthus annuus*	Common sunflower	Netherlands	13-27	5.8	10
32			Java	28-36	7.8	10
33	*Hordeum* sp.	Barley	Pamirs	....	>30	1
34	*Lycopersicon esculentum*	Tomato	Southern Sweden	20	16.8	28
35	*Malus pumila*	Common apple	Ohio	26	20 (20)	2
36	*Medicago sativa*	Alfalfa	Central Asia	....	22.4	17
37	*Nicotiana tabacum*	Common tobacco	USSR	25	8.40	24,25
38	*Phaseolus vulgaris*	Kidney bean	Sweden	....	17.0	30
39	*Phleum pratense*	Timothy	USSR	17-20	23	16
40	*Phoenix dactylifera*	Date palm	Algeria	....	3.4	11
41	*Prunus laurocerasus*	Laurel cherry	Germany	-3 to 0	0.054[2]	31
42			Germany	3-12	0.34[2]	31
43	*Quercus ilex*	Holly oak	Italy	12-14	65.7[3]	29
44	*Q. lyrata*	Overcup oak	Massachusetts	....	(10.8)	18
45	*Rheum officinale*	Medicinal rhubarb	Germany	....	19[3]	26
46	*Rhododendron brachycarpum*	Fujiyama rhododendron	Japan	....	(2.8)	13
47	*Salix glauca*	Gray-leaf willow	Greenland	10	4	23
48			Greenland	20	6	23
49	*Sambucus nigra*	European elder	Denmark	20	4.6 (1.7)	3
50	*Solanum tuberosum*	Potato	Southern Sweden	20	19.2	28
51	*Trifolium pratense*	Red clover	USSR	20-29	24	16
52	*Triticum aestivum*	Wheat	Central Asia	....	36.5	17
53			Germany	-6 to 0	0.52[2]	31
54			Germany	0-6	1.67[2]	31
55	*Vicia sativa*	Vetch	USSR	....	12.21	15
56	*Vitis vinifera*	European grape	Central Asia	....	16.1	17
57	*Zea mays*	Corn	USSR	25	10.02	25

/1/ mg CO_2 per g fresh weight per hour. /2/ mg CO_2 per g dry weight per hour. /3/ Calculated from the assay of assimilates, assuming an empirical formula of CH_2O.

continued

69. PHOTOSYNTHESIS: APPARENT RATES

Part I. MAXIMUM RATES: NATURAL CONDITIONS, VARIOUS LOCALES

Contributors: (a) Siegel, Jack M., (b) Olson, Rodney A.

References: [1] Blagoveshchenskij, A. V. 1935. Planta 24:276. [2] Böhning, R. H. 1949. Plant Physiol. 24:222. [3] Boysen-Jensen, P. 1919. Botan. Tidsskr. 36:219. [4] Boysen-Jensen, P. 1932. Stoffproduktion der Pflanzen. G. Fischer, Jena. [5] Boysen-Jensen, P., and D. Müller. 1929. Jahrb. Wiss. Botan. 70:493. [6] Boysen-Jensen, P., and D. Müller. 1929. Ibid. 70:503. [7] Brown, H. T., and F. Escombe. 1905. Proc. Roy. Soc. (London), B, 76:29. [8] Chrelashvili, M. N. 1941. Tr. Botan. Inst. Akad. Nauk SSSR, IV, 5:101. [9] Filippenko, I. A., E. H. Gerber, and O. K. Elpidina. 1937. Compt. Rend. Acad. Sci. URSS 17:323. [10] Giltay, E. 1898. Ann. Jard. Botan. Buitenzorg 15:43. [11] Harder, R., P. Filzer, and A. Lorenz. 1932. Jahrb. Wiss. Botan. 75:45. [12] Henrici, M. 1921. Verhandl. Naturforsch. Ges. Basel 32:107. [13] Hiramatsu, K. 1932. Sci. Rept. Tohoku Imp. Univ., Ser. 2, 7:239. [14] Johansson, N. 1926. Svensk Botan. Tidskr. 20:107. [15] Kniep, H. 1914. Intern. Rev. Ges. Hydrobiol. Hydrog. 7:1. [16] Kostychev, S., K. Bazyrina, and G. Vasiliev. 1927. Biochem. Z. 182:79. [17] Kostychev, S., and H. Kardo-Sysojeva. 1930. Planta 11:117. [18] Kozlowski, T. T. 1949. Ecol. Monographs 19:207. [19] Kramer, P. J., and W. S. Clark. 1947. Plant Physiol. 22:51. [20] Lundegårdh, H. 1924. Biochem. Z. 154:195. [21] Lundegårdh, H. 1924. Medd. Centralanstalt. Foersoeksvaesendet Jordbruks. 331. [22] Maximov, N. A., and T. A. Krasnoselskaja-Maximova. 1928. Ber. Deut. Botan. Ges. 46:383. [23] Müller, D. 1928. Planta 6:22. [24] Richter, A. A., K. T. Sukhorukov, and L. A. Ostapenko. 1945. Compt. Rend. Acad. Sci. URSS 46:40. [25] Richter, A. A., K. T. Sukhorukov, and L. A. Ostapenko. 1945. Ibid. 46:165. [26] Sachs, J. 1884. Arb. Botan. Inst. Wuerzburg 3:1. [27] Stålfelt, M. G. 1921. Medd. Statens Skogsfoersoeksanstalt (Stockholm) 18:221. [28] Stöcker, O. 1927. Flora (Jena) 121:334. [29] Von Guttenberg, H. 1927. Planta 4:726. [30] Yoshii, Y. 1928. Ibid. 6:22. [31] Zeller, O. 1951. Ibid. 39:500. [32] Zhdanova, L. P. 1944. Compt. Rend. Acad. Sci. URSS 45:353.

Part II. MAXIMUM RATES: NEAR-OPTIMUM CONDITIONS

Values are uncorrected for respiration.

	Species	Common Name	CO_2 in Air %	Temp. °C	CO_2 Fixation, g CO_2/hr per 100 g wet wt	per 100 g dry wt	per sq dm x 1000	per g chlorophyll ($\sqrt{A}$)[1]	Assimilation Time (T_A)[2] sec	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Algae									
	Chlorella pyrenoidosa[3]	Chlorella								
1	In light		...	...	...	13.4	...	2.8	56	3
2	In shade		...	...	...	11.5	...	4.1	36	3
3	*Gigartina harveyana*[4]	Seaweed	...	16	...	...	14	...	...	1
4	*Hormidium flaccidum*	Water net	...	20	...	...	...	6.8	23	4
5	*Ulva lactuca*	Sea lettuce	...	25	...	...	11.8	...	...	2
	Angiospermae									
	Acer pseudoplatanus	Plane-tree maple								
6	Young leaves		5	25	0.98	3.0	16	11.8	13	5
7	Old leaves		5	25	2.07	5.8	26	5.2	30	5
8	*Helianthus annuus*	Common sunflower	5	25	2.30	13.4	80	14.0	11	5
9	*Populus alba*	White poplar	5	25	1.90	6.0	40	10.0	16	5
	Sambucus nigra	European elder								
10	Green leaves		5	25	1.96	5.3	34	6.6	24	5
11	Yellow leaves		5	25	0.88	4.7	18	120	1.3	5
12	*Tilia cordata*	Little-leaf linden	5	25	1.88	5.8	28	6.6	24	5

/1/ $\sqrt{A}$, the assimilation number, is the maximum quantity of CO_2 that can be reduced in unit time by unit quantity of chlorophyll. /2/ The shortest time in which one molecule of chlorophyll can reduce one molecule of CO_2. /3/ In carbonate buffer 9. /4/ In artificial seawater.

continued

69. PHOTOSYNTHESIS: APPARENT RATES

Part II. MAXIMUM RATES: NEAR - OPTIMUM CONDITIONS

Contributor: Olson, Rodney A.

References: [1] Emerson, R., and L. Green. 1934. J. Gen. Physiol. 17:817. [2] Kniep, H. 1914. Intern. Rev. Ges. Hydrobiol. Hydrog. 7:1. [3] Noddack, W., and C. Kopp. 1940. Z. Physik. Chem., A, 187:79. [4] Van der Honert, T. H. 1930. Rev. Trav. Botan. Neerl. 27:149. [5] Willstätter, R., and A. Stoll. 1918. Untersuchungen über die Assimilation der Kohlensäure. J. Springer, Berlin.

Part III. AVERAGE RATES

Values are uncorrected for respiration. Values in parentheses are maximum rates. **Temp.** (column C): N = under natural conditions.

	Species	Common Name	Conditions			Photosynthesis rate/hr	Reference
			Temp. °C	Light ft-c	CO_2 in Air		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Algae						
1	*Chlorella saccharophila*	Chlorella	22.4	2,480	Buffer 9/1/	452.3 mm^3 O_2/100 million cells	19
2	*C. vulgaris viridis*	Chlorella	22.4	2,480	Buffer 9/1/	194.7 mm^3 O_2/100 million cells	19
3	*Cladophora glomerata*	Cladophora	17	....	....	0.3 moles $CO_2/10\mu^3$	15
4	*Nostoc muscorum*	Nostoc	25	1,000	Buffer 9/1/	13.2 ml O_2/ml packed cells	2
	Bryophyta						
5	*Hylocomium proliferum*	Hylocomium	....	93-186	....	1.25-3 mg CO_2/g dry wt	6
6	*Sphagnum girgensohnii*	Sphagnum moss	....	110-260	....	2.75 mg CO_2/g dry wt	6
	Gymnospermae						
7	*Picea pungens*	Colorado spruce	24	2,200	Natural	0.03 mg CO_2/100 leaves	4
8	*Pinus taeda*	Loblolly pine	30	2,000	Natural	2 (3.9) mg CO_2/dm^2	8
	Angiospermae						
9	*Citrus limon*	Lemon	....	1,300	1.5%	3-5 ml O_2/dm^2	17
10	*C. sinensis*	Sweet orange	....	1,300	1.5%	4-6 ml O_2/dm^2	17
11	*Cornus florida*	Flowering dogwood	30	2,000	Natural	2 (3.06) mg CO_2/dm^2	8
12	*Cucurbita pepo*	Pumpkin	....	....	....	0.68 g/M^2 increase in dry wt	13
13	*Helianthus annuus*	Common sunflower	....	4,460	5%	(80) mg CO_2/dm^2	18
14	*Hordeum vulgare*	Barley	N	500	Natural	9-16 mg CO_2/dm^2	5
15	*Lycopersicon esculentum*	Tomato	....	....	....	16.5-18.6 mg CO_2/dm^2	10
16	*Malus sylvestris*	Apple	N	Natural	Natural	6.6 mg CO_2/dm^2	7
17	*Medicago sativa*	Alfalfa	N	Noon sun	Natural	0.75 (1.042) g/6 x 6 ft plot	14
18	*Oryza sativa*	Rice	31	1.74 cal/cm/min	Natural	9-20 mg CO_2/M^2	11
19	*Phaseolus vulgaris*	Kidney bean	25	1,400	Natural	5.8-16.6 mg CO_2/dm^2	1
20	*Prunus laurocerasus*	Laurel cherry	29.5	Noon sun	Natural	23.2 mg CO_2/dm^2	9
21	*P. persica*	Peach	N	Natural	Natural	0.146-0.18 g/M^2 increase in dry wt	12
22	*Quercus rubra*	Eastern red oak	30	2,000	Natural	5 (6.04) mg CO_2/dm^2	8
23	*Rheum rhaponticum*	Garden rhubarb	....	....	....	0.65 g/M^2 increase in dry wt	13
24	*Solanum tuberosum*	Potato	N	>5,000	Natural	16-20 mg CO_2/dm^2	3
25	*Zea mays*	Corn	N	Full sun	Natural	1.8 g CO_2/M^2 leaf	16

/1/ Carbonate buffer 9.

Contributor: Bing, Arthur

References: [1] Bing, A. Unpublished. Cornell Univ. Ornamentals Research Laboratory, N. Y., 1953. [2] Brown, T. E. 1954. Ph.D. Thesis. Ohio State Univ., Columbus. [3] Chapman, H. W. 1951. Am. Potato J. 28(5):602. [4] Freeland, R. O. 1952. Plant Physiol. 27(4):685. [5] Gregory, F. G., and F. J. Richards. 1929. Ann. Botany (London) 43:119. [6] Harder, R. 1930. Planta 11:263. [7] Heinicke, A. J., and M. B. Hoffman. 1933. Cornell

continued

69. PHOTOSYNTHESIS: APPARENT RATES

Part III. AVERAGE RATES

Univ. Agr. Expt. Sta. Bull. 577. [8] Kramer, P. J., and J. P. Decker. 1944. Plant Physiol. 19(2):350. [9] Matthaei, G. L. C. 1905. Phil. Trans. Roy. Soc. London, B. 197:47. [10] Mitchell, J. W. 1936. Botan. Gaz. 98:87. [11] Noguti, Y. 1941. Japan. J. Botany 11(2):167. [12] Pickett, W. F., A. S. Fish, and W. S. Shan. 1951. Proc. Am. Soc. Hort. Sci. 57:111. [13] Sachs, J. 1884. Arb. Botan. Inst. Wuerzburg 3:1. [14] Thomas, M. D., and G. R. Hill. 1937. Plant Physiol. 12:285. [15] Verduin, J. 1952. Am. J. Botany 39(3):157. [16] Verduin, J., and W. E. Loomis. 1944. Plant Physiol. 19:278. [17] Wedding, R. T., L. A. Riehl, and W. H. Rhoads. 1952. Ibid. 27(2):269. [18] Willstätter, R., and A. Stoll. 1918. Untersuchungen über die Assimilation der Kohlensäure. J. Springer, Berlin. [19] Winokur, M. 1948. Am. J. Botany 35(5):207.

70. CARBON PRODUCTION AND PHOTOSYNTHETIC EFFICIENCY

Part I. ESTIMATED ANNUAL CARBON PRODUCTION

	Region	Area sq km	Carbon Fixed ton/yr: per sq km	Carbon Fixed ton/yr: Total	Reference
	(A)	(B)	(C)	(D)	(E)
1	Forest	44×10^6	250	11×10^9	1
2	Cultivated land	27×10^6	160	4.3×10^9	1
3	Grassland	31×10^6	36	1.1×10^9	1
4	Desert	47×10^6	7	0.3×10^9	1
5	Total land	149×10^6		16.7×10^9	1
6	Ocean	371×10^6	340	126×10^9 /1/	2

/1/ 16×10^9 also reported [3].

Contributor: Bohning, Richard H.

References: [1] Rabinowitch, E. I. 1945. Photosynthesis. Interscience, New York. v. 1, p. 6. [2] Riley, G. A. 1944. Am. Scientist 32:129. [3] Steemann-Nielsen, E. 1952. Nature 169:956.

Part II. ENERGY UTILIZATION IN PHOTOSYNTHESIS

	Specification	Value	Reference
	(A)	(B)	(C)
1	Energy utilized in photosynthesis by one acre of corn plants to produce 8,732 kg glucose[1]	3.3×10^7 kcal	2
2	Total solar energy available on the acre during growing season	2.043×10^9 kcal	2
3	Photosynthetic efficiency of corn plants, i.e., percent of available energy used in photosynthesis	1.6%	2
4	Energy equivalent of earth's carbon production	$(13.6 \pm 8.1) \times 10^{17}$ kcal	1
5	Mean solar radiation	7.4×10^{20} kcal	1
6	Photosynthetic efficiency of the world	0.18 ± 0.12%	1

/1/ Total sugar, as glucose, manufactured by one acre of corn plants.

Contributor: Bohning, Richard H.

References: [1] Riley, G. A. 1944. Am. Scientist 32:129. [2] Transeau, E. N. 1926. Ohio J. Sci. 26:1.

71. NITROGEN FIXATION

Part I. RHIZOBIA-INOCULATED LEGUMES

The amount of nitrogen fixed from the air by the symbiotic relationship of rhizobia with legumes is influenced by the effectiveness of the rhizobia, host species, soil and climatic conditions, and individual crop handling. Values in parentheses are ranges, estimate "c" (cf. Introduction).

	Rhizobium and Host	N_2 Fixed kg/acre
	(A)	(B)
	Rhizobium spp.	
1	*Arachis hypogaea* (peanut)	19
2	*Cicer arietinum* (garbanzo)	30
3	*Lespedeza* spp.[1] (lespedeza)	39(15-94)
4	*Pueraria thunbergiana* (kudzu)	49(40-57)
	Rhizobium spp.	
5	*Stizolobium deeringianum* (Florida velvet bean)	30
6	*Vigna sinensis* (cowpea)	41(26-53)
7	Pastures with legumes	48(5-91)

/1/ *L. striata* (common lespedeza) and *L. stipulacea* (Korean lespedeza).

continued

71. NITROGEN FIXATION

Part I. RHIZOBIA-INOCULATED LEGUMES

	Rhizobium and Host	N_2 Fixed kg/acre
	(A)	(B)
	Rhizobium japonicum	
8	*Glycine soja* (soybean)	26(7-48)
	R. leguminosarum	
9	*Lens culinaris* (lentil)	47
10	*Pisum sativum* (garden pea)	33(13-60)
11	*P. sativum arvense* (field pea)	23(20-28)
12	*Vicia* spp. (vetch)	36(20-63)
	R. lupini	
13	*Lupinus angustifolius* (lupine)	68
	R. meliloti	
14	*Medicago hispida denticulata* (toothed bur clover)	35(23-49)
	Rhizobium meliloti	
15	*Medicago sativa* (alfalfa)	88(25-170)
16	*Melilotus alba* (white sweet clover)	54(30-75)
17	*M. indica* (annual yellow sweet clover)	45
18	*Trigonella foenum-graecum* (fenugreek)	37
	R. phaseoli	
19	*Phaseolus vulgaris* (kidney bean)	18
	R. trifolii	
20	*Trifolium incarnatum* (crimson clover)	42(32-53)
21	*T. pratense* (red clover)	52(19-78)
22	*T. repens* (white clover)	47(35-65)
23	*T. repens giganteum* (white clover)	81(72-91)

Contributor: Erdman, Lewis W.

Reference: Erdman, L. W. 1948. U. S. Dept. Agr. Farmers' Bull. 2003.

Part II. CHARACTERISTICS OF NITROGEN-FIXING ORGANISMS

	Organism	Essential Host	Oxygen	Nourishment	Limiting pH	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
	Bacteria					
1	*Azotobacter*[1]	None	Aerobic	Heterotrophic	2.9-9.2	4,5,8,18,21
2	*Chlorobacterium*	None	Anaerobic	Heterotrophic	ca. 7.0	4,16
3	*Chromatium*	None	Anaerobic	Autotrophic	ca. 7.0	4,16
4	*Clostridium*[2]	None	Anaerobic	Heterotrophic	[illegible]-8.0	4,6,15,22
5	*Desulfovibrio*	None	Anaerobic	Heterotrophic	7.0	4,19
6	*Rhizobium* spp.[3]	*Vigna, Lespedeza*	Aerobic±	Heterotrophic	[illegible]	1-4,7,11-14,18
7	*R. japonicum*[3]	*Glycine*	Aerobic	Heterotrophic	3.3	1-4,7,11-14,18
8	*R. leguminosarum*[3]	*Pisum*	Aerobic	Heterotrophic	4.7	1-4,7,11-14,18
9	*R. lupini*	*Lupinus*	Aerobic	Heterotropbic	3.15	1-4,7,11-14,18
10	*R. meliloti*[1,3]	*Medicago, Melilotus*	Aerobic	Heterotrophic	4.9	1-4,7,11-14,18
11	*R. phaseoli*[3]	*Phaseolus*	Aerobic	Heterotrophic	4.2	1-4,7,11-14,18
12	*R. trifolii*[3]	*Trifolium*	Aerobic	Heterotrophic	4.2	1-4,7,11-14,18
13	*Rhodomicrobium*	None	Anaerobic	Heterotrophic	ca. 7.0	4,9,17
14	*Rhodopseudomonas*	None	Anaerobic[4]	Heterotrophic	ca. 7.0	4,9,16,17
15	*Rhodospirillum*	None	Anaerobic[4]	Heterotrophic	ca. 7.0	4,9,16,17
	Algae					
16	*Calothrix*[1]	None	Aerobic	Autotrophic	5.7-8.5	4-6,10,20
17	*Nostoc*[1]	None	Aerobic	Autotrophic	5.7-8.5	4-6,10,20

/1/ Inhibited by NH_4 and NO_3, stimulated by Mo. /2/ Inhibited by NH_4, stimulated by Mo. /3/ N_2 fixation inhibited by 2,4-D and by seed treatments containing Cu; slightly inhibited by DDT. /4/ Fixation is best under anaerobic conditions in light, slight under aerobic conditions in dark. Organism is facultative.

Contributor: Appleman, Milo D.

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continued

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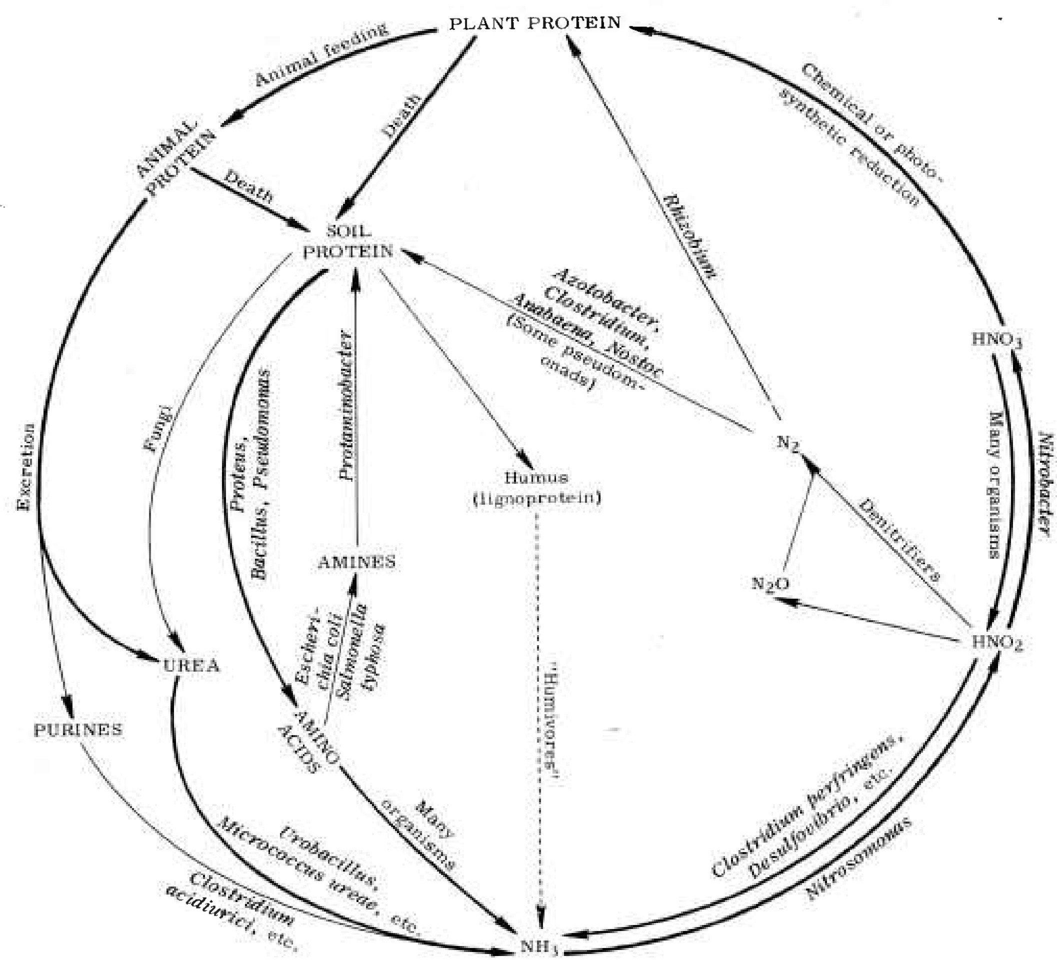
72. NITROGEN CYCLE IN NATURE



Contributor: Thimann, Kenneth V.

Reference: Thimann, K. V. 1963. The life of bacteria. Ed. 2. Macmillan, New York.

VII. RESPIRATION AND CIRCULATION

73. CHARACTERISTICS OF RESPIRATORY MEDIA

Water and nitrogen are the two major ecological variations in the respiratory media available to organisms. The aqueous or gaseous solvent (water or nitrogen), through which the exchange of O_2 and CO_2 occurs, is the primary substance that actively ventilates the respiratory organ. The solvent is mechanically inspired by the animal. STP = standard temperature and pressure.

	Variable	Media			
		Aquatic		Atmospheric	
		Ocean	Fresh	Sea Level	6,000 Meters
	(A)	(B)	(C)	(D)	(E)
1	Temperature, °C	-2.0 to +30.0	2.0-32.0	0.7-15.7[1]	-28.1 to -15.1
2	Pressure, total, mm Hg	760-760,000	760-20,000	760	347.5-360.2
3	Density, g/liter	1,027[3] (20°C)	1,000[3] (4°C)	1.223-1.290[3]	0.649-0.659[3]
	Concentration				
4	H_2O, vol %	100.00[4]	100.00[4]	1.00[5]	1.00[5]
5	N_2, vol %	1.03[2] (15°C)	1.33[2] (15°C)	78.03 (STP)	78.03 (STP)
6	CO_2, vol %	0.02[2] (15°C)	0.03[2] (15°C)	0.03 (STP)	0.03 (STP)
7	O_2, vol %	0.58[2] (15°C)	0.72[2] (15°C)	20.95 (STP)	20.95 (STP)
8	Salts, °/oo	34.48[2]	0.18[2]	....	....
9	pH	7.5-8.4	3.2-10.6	....	....
10	Inert gases, vol %	Traces	Traces	0.95 (STP)	0.95 (STP)
	Partial Pressure (Tension)[6]				
11	H_2O, mm Hg	12.79 (15°C)	6.10 (4°C)	6.40[7] (15°C)	0.72[7] (-15°C)
12	N_2, mm Hg	593.02 (STP)	593.02 (STP)	593.02 (STP)	281.06[8] (STP)
13	CO_2, mm Hg	0.23[2] (STP)	0.23[2] (STP)	0.23 (STP)	0.11[8] (STP)
14	O_2, mm Hg	159.52[2] (STP)	159.52[2] (STP)	159.52 (STP)	75.61[8] (STP)
15	Inert gases, mm Hg	7.46 (STP)	7.46 (STP)	7.46 (STP)	3.42[8] (STP)
	Diffusion Coefficient (ml/min/sq cm/cm distance at 760 mm Hg, 20°C)				
16	N_2	....	0.000018[9] (0.53)[10]	....	....
17	CO_2	....	0.000785[9] (23.1)[10]	....	....
18	O_2	....	0.000034 (1)[10]	11.0	....

/1/ Actual range is much wider. /2/ Average of many determinations; varies widely with conditions of measurement. /3/ Density determined at temperatures given in line 1. /4/ Less volume of solutes. /5/ Varies but never absent, and always of biological significance. /6/ Only for water in equilibrium with the atmosphere, as at the surface of ocean or lake. /7/ Calculated for 50% relative humidity. /8/ Calculated. /9/ Calculated from measured value for O_2 (line 18) and relative coefficients (lines 16 and 17). /10/ Values in parentheses are relative coefficients, with O_2 as unity.

Contributor: McCutcheon, F. Harold

References: [1] Heilbrunn, L. V. 1952. General physiology. W. B. Saunders, Philadelphia. [2] Hodgman, C. D., ed. 1956-57. Handbook of chemistry and physics. Chemical Rubber, Clevcland. [3] Krogh, A. 1919. J. Physiol. (London) 52:391. [4] Pearse, A. S. 1939. Animal ecology. McGraw-Hill, New York. [5] Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. 1946. The oceans. Prentice-Hall, New York.

74. LUNG VENTILATION: VERTEBRATES

Values, unless otherwise indicated, are for adult animals at rest. Values in parentheses are ranges, estimate "c" unless otherwise indicated (cf. Introduction).

	Species	Common Name	Sex and Body Weight kg	Respiratory Rate breaths/min	Tidal Volume[1] ml	Minute Volume liters/min	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
				Mammalia			
	Homo sapiens	Man					
1		Premature	1.97(1.41-2.53)[b]	34.4(17.2-51.6)[b]	12.3(4.1-20.5)[b]	0.396(0.204-0.588)[b]	3
2		Newborn	3.4(2.5-4.3)[b]	28.6(18.2-39.0)[b]	20.7(13.5-27.9)[b]	0.584(0.471-0.697)[b]	3
3		Adult	♂ 68.5	11.7(10.1-13.1)	750(575-895)	7.43(5.8-10.3)	12
4				17.1(15.7-18.2)[2]	1,673(1,510-1,770)[2]	28.6(27.3-30.9)[2]	12
5				21.2(18.6-23.3)[3]	2,030(1,900-2,110)[3]	42.9(39.3-45.2)[3]	12
6			♀ 54.0	11.7(10.4-13.0)	339(285-393)	4.5(4.0-5.1)	12
7				19[2]	860(836-885)[2]	16.3(15.9-16.8)[2]	12
8				30.0(25.0-35.3)[3]	880(490-1,270)[3]	24.5(17.3-31.8)[3]	12
9	*Bos taurus*	Cattle	♀ (403-514)	30[4]	(2,700-3,400)[4]	(82-104)[4]	5
10				(27-29)[5]	(3,400-4,200)[5]	(92-114)[5]	5
11	*Canis familiaris*	Dog[6]	(16.4-30.5)	18(11-37)	320(251-432)	5.21(3.3-7.4)	6
12	*Capra hircus*	Goat	....	19	310	5.7	1
13	*Cavia porcellus*	Guinea pig	0.466(0.274-0.941)	90(69-104)	1.8(1.0-3.9)	0.16(0.10-0.38)	4
14	*Equus caballus*	Horse[7]	696	11.9(10.6-13.6)	9,060(8,520-9,680)	107	2
15	*Felis catus*	Cat	2.45	26	12.4	0.322	13
16	*Macaca mulatta*	Rhesus monkey	2.68(2.05-3.08)	40(31-52)	21.0(9.8-29.0)	0.86(0.31-1.41)	4
17	*Mesocricetus auratus*	Golden hamster	0.092(0.065-0.134)	74(33-127)	0.8(0.42-1.2)	0.06(0.033-0.083)	4
18	*Mus musculus*	House mouse	0.020(0.012-0.026)	163(84-230)	0.15(0.09-0.23)	0.024(0.011-0.036)	4
19	*Oryctolagus cuniculus*	European rabbit	....	51(38-60)	21.0(19.3-24.6)	1.07(0.80-1.14)	4,8, 9,14
20	*Phoca vitulina*	Harbor seal	27.5	9(6-12)[8]	....	3.97[8]	7
21	*Rattus norvegicus*	Norway rat	0.113(0.063-0.152)	85.5(66-114)	0.86(0.60-1.25)	0.073(0.05-0.101)	4
22	*Sus scrofa*	Swine	♂ 225	....	....	37	2
				Aves			
23	*Anas* sp.	Duck	♂	42	(35-38)[9]	....	11
24			♀	110	....	....	11
25	*Anser* sp.	Goose	♂	20	....	....	11
26			♀	40	....	....	11
27	*Columba livia*	Street pigeon	....	(25-30)	(4.5-5.2)[10]	....	11
28	*Gallus domesticus*	Chicken	♂	(12-21)	45	....	11
29			♀	(20-37)	....	....	11
30	*Meleagris gallopavo*	Turkey	♂	28	....	....	11
31			♀	49	....	....	11
32	*Serinus canarius*	Canary	....	(96-120)	....	....	11
				Reptilia			
33	*Malaclemys terrapin centrata*	Southern diamondback terrapin	(0.65-0.72)	3.7[11]	14[11]	0.051[11]	10

/1/ Air inspired or expired in one respiration. /2/ Light work. /3/ Heavy work. /4/ Lying. /5/ Standing. /6/ Measurements made after 30-minute rest in hammock at 24°C; values corrected to BTPS conditions (gas at body temperature and atmospheric pressure, completely saturated with water vapor). /7/ Percheron gelding. /8/ Cheyne-Stokes respiration. /9/ Standing; supine, 30. /10/ Standing; supine, 4.7. /11/ At (24-29)°C.

Contributors: (a) Stroud, Robert, and Forster, Robert E., (b) Elisberg, Edward I., (c) Hemingway, Allan

References: [1] Barcroft, J., et al. 1919. Quart. J. Med. 13:35. [2] Brody, S. 1945. Bioenergetics and growth. Reinhold, New York. [3] Cross, K. W. 1953. Ph.D. Thesis. Univ. London, England. [4] Guyton, A. C. 1947. Am. J. Physiol. 150:70. [5] Hall, W. C., and S. Brody. 1933. Missouri Univ. Agr. Expt. Sta. Res. Bull. 180:11. [6] Hemingway, A., and G. S. Nahas. Unpublished. Univ. California, Los Angeles, 1953. [7] Irving, L., et al. 1936. J. Cellular Comp. Physiol. 7:137. [8] Leegard, F. 1927. Acta Med. Scand. 67:401. [9] Leegard, F. 1930.

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75. OXYGEN CONSUMPTION

Oxygen consumption values should be used with caution, as the figures reflect order of magnitude only.

Part I. MAMMALS

Values are cubic millimeters oxygen per gram fresh weight per hour for adult animals.

	Species	Common Name	Rate	Reference
	(A)	(B)	(C)	(D)
1	*Homo sapiens*	Man	220[1]	2
2			4,000[2]	10
3	*Bos taurus*	Cattle, ♀	184	2
4			390	3,14
5	*Canis familiaris*	Dog	580	3
6	*Cavia* sp.	Guinea pig	816	2
7	*Citellus undulatus parryi*	Parry's Arctic ground squirrel	600	13
8	*Dasypus* sp.	Armadillo	201	12
9	*Elephas maximus*	Asiatic elephant, ♀[3]	155	1
10	*Equus caballus*	Horse	250	3
11	*Felis catus*	Cat	710	3
12	*Mesocricetus auratus*	Golden hamster	2,900[4]	5
13			70[5]	5
14	*Mus musculus*	House mouse	3,500[1]	8
15			1,530[6]	7
16	*Mustela rixosa*	Least weasel	5,000	13
17	*Myotis lucifugus*	Little brown bat	1,500	8
18	*Ornithorhynchus* sp.	Platypus	460	6
19	*Oryctolagus cuniculus*	European rabbit	640-850	3
20	*Ovis aries*	Sheep	220	2
21			340	3,14
22	*Phoca vitulina*	Harbor seal	540	4
23	*Phocaena phocaena*	Harbor porpoise	300	11
24	*Procyon cancrivorus*	Crab-eating raccoon	395	13
25	*Rattus* sp.	Rat	2,000	6
26	*Sorex cinereus*	Gray shrew	13,700	9
27	*Sus scrofa*	Swine	220	14

/1/ Resting. /2/ Maximum work. /3/ 37 years old. /4/ Awake. /5/ Hibernating. /6/ Basal.

Contributor: Flemister, Launce J.

References: [1] Benedict, F. G. 1936. The physiology of the elephant. Carnegie Institution of Washington, Washington, D. C. [2] Brody, S. 1945. Bioenergetics and growth. Reinhold, New York. [3] Heilbrunn, L. V. 1952. An outline of general physiology. Ed. 3. W. B. Saunders, Philadelphia. [4] Irving, L., et al. 1935. J. Cellular Comp. Physiol. 7:137. [5] Lyman, C. P. 1948. J. Exptl. Zool. 109:55. [6] Martin, C. J. 1903. Phil. Trans. Roy. Soc. London, B, 195:1. [7] Morrison, P. R. 1948. J. Cellular Comp. Physiol. 31:281. [8] Pearson, O. P. 1947. Ecology 28:127. [9] Pearson, O. P. 1948. Science 108:44. [10] Robinson, S., A. T. Edwards, and D. B. Dill. 1937. Ibid. 85:409. [11] Scholander, P. F. 1940. Hvalradets Skrifter Norske Videnskaps-Akad. Oslo 22. [12] Scholander, P. F., et al. 1943. J. Cellular Comp. Physiol. 21:53. [13] Scholander, P. F., et al. 1950. Biol. Bull. 99:259. [14] Voit, E. 1901. Z. Biol. 41:113.

Part II. VERTEBRATES OTHER THAN MAMMALS

Values are cubic millimeters oxygen per gram fresh weight per hour for adult animals.

	Species	Common Name	Temp., °C	Rate	Reference
	(A)	(B)	(C)	(D)	(E)
		Aves			
1	*Anas* sp.	Duck	....	800	8
2	*Anser* sp.	Goose	....	592	21

continued

75. OXYGEN CONSUMPTION

Part II. VERTEBRATES OTHER THAN MAMMALS

	Species	Common Name	Temp., °C	Rate	Reference
	(A)	(B)	(C)	(D)	(E)
		Aves			
3	*Columba* sp.	Pigeon	....	710	15
4	*Corvus corax*	Raven[1]	....	940	17
5	*Gallus domesticus*	Chicken	....	497	4
6	*Larus hyperboreus*	Glaucous gull	....	1,640	17
7	*Passer domesticus*	House sparrow	....	2,100	3
8	*Selasphorus sasin*	Allen's hummingbird	22	13,900	14
9	*Serinus canarius*	Canary	....	2,900	3
		Reptilia			
10	*Alligator mississipiensis*	American alligator	22; 19.5	8.9; 7.5	2
11	*Anguis fragilis*	Slowworm	20	40	20
12	*Crotalus atrox*	Western diamondback rattlesnake	30; 22	35.5; 16.4	19
13	*Iguana tuberculata*	Iguana, tuberculate	30; 22	52.0; 22.2	2
14	*Malaclemys terrapin centrata*	Southern diamondback terrapin	24	35	12
15	*Natrix natrix*	European water snake	20	92-150	6,9
		Amphibia			
16	*Rana esculenta*	Edible frog	20	85[2]	5
17			20	437[3]	5
18	*Triturus* sp.	Newt	20	110	9
		Pisces			
19	*Anguilla anguilla*	European freshwater eel	25	128	13
20	*Carassius auratus*	Goldfish	20	85[4]	7
21			20	160[5]	7
22	*Cyprinus carpio*	Carp	19.5	100	10
23	*Esox lucius*	Northern pike	18	102	11
24	*Lepidosiren paradoxa*	South American lungfish	20	42	16
25	*Protopterus aethiopicus*	East African lungfish	20	52[6]	18
26			20	10[7]	18
27	*Salmo trutta*	Brown trout	15	226	11
28	*Scomber scombrus*	Atlantic mackerel	20	726	1

/1/ Arctic. /2/ Winter. /3/ Summer. /4/ Resting. /5/ Active. /6/ Feeding. /7/ Fasting.

Contributor: Flemister, Launce J.

References: [1] Baldwin, F. M. 1924. Proc. Iowa Acad. Sci. 30:173. [2] Benedict, F. G. 1932. Carnegie Inst. Wash. Publ. 425. [3] Benedict, F. G., and E. L. Fox. 1933. Arch. Ges. Physiol. 232:357. [4] Benedict, F. G., W. Landauer, and E. L. Fox. 1932. Conn. Univ. Storrs Agr. Expt. Sta. Bull. 177:1. [5] Bohr, C. 1899. Skand. Arch. Physiol. 10:74. [6] Cohnheim, O. 1912. Z. Physiol. Chem. 76:298. [7] Fry, F. E., and J. S. Hart. 1948. Biol. Bull. 94:66. [8] Hari, Y., and A. Kriwuscha. 1918. Biochem. Z. 88:345. [9] Hill, A. V. 1911. J. Physiol. (London) 43:379. [10] Knauthe, K. 1898. Arch. Ges. Physiol. 73:490. [11] Lindstedt, P. 1914. Z. Fischerei 14:193. [12] McCutcheon, F. H. 1943. Physiol. Zool. 16:255. [13] Montuori, A. 1913. Arch. Ital. Biol. 59:213. [14] Pearson, O. P. 1950. Condor 52:145. [15] Riddle, O. 1932. Missouri Univ. Agr. Expt. Sta. Res. Bull. 166:86. [16] Sawaya, P. 1946. Univ. Sao Paulo Fac. Filosof. Cienc. Letras, Zool., Bol. 11:255. [17] Scholander, P. F., et al. 1950. Biol. Bull. 99:259. [18] Smith, H. W. 1935. J. Cellular Comp. Physiol. 6:43. [19] Sumner, F. B., and U. N. Lanham. 1942. Biol. Bull. 82:313. [20] Vernon, H. M. 1897. J. Physiol. (London) 21:443. [21] Voit, E. 1901. Z. Biol. 41:113.

continued

75. OXYGEN CONSUMPTION

Part III. INVERTEBRATES OTHER THAN PROTOZOA

Values are cubic millimeters oxygen per gram fresh weight per hour for adult animals.

	Class	Species	Common Name	Temp., °C	Rate	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
			Chordata			
1	Cephalochordata[1]	*Branchiostoma lanceolatum*	Amphioxus	20; 16	45; 35	25
2	Ascidiacea	*Ascidia mentula*	Sea squirt	25	4.8	19
			Echinodermata			
3	Ophiuroidea	*Ophioderma longicauda*	Brittle star	25	8-32	7,19
4	Asteroidea	*Asterias rubens*	Starfish	15	21[2]	3
5				15	24[3]	
6	Holothuroidea	*Holothuria impatiens*	Sea cucumber	25	17	19
			Arthropoda			
7	Crustacea	*Astacus fluviatilis*	Crayfish	15	30	16
8		*Carcinus maenas*	Shore crab	15	625	19
9		*Homarus americanus*	American lobster	15	507	5
10	Insecta	*Aedes aegypti*	Yellow-fever mosquito	26	♂2,330; ♀4,200	18
11		*Apis mellifera*	Honeybee	20	17,466[4]	20
12				20	87,000[5]	12
13		*Blatta orientalis*	Oriental cockroach	25; 20	450; 277	8,26
14		*Drosophila* sp.	Fruit fly	20	1,560[4]	6
15				20	21,800[5]	
16		*Formica* sp.	Ant	20	532	21
17		*Melolontha* sp.	June beetle	20	960	2
18		*Musca domestica*	Housefly	20	1,980	10
19		*Phaenicia sericata*	Greenbottle fly	20	95,600	9
20	Onychophora	*Peripatus accacioi*	Peripatus	30; 20; 10	226; 92; 37	17
			Annelida			
21	Oligochaeta	*Lumbricus terrestris*	Earthworm	20.5	138	13
22	Polychaeta	*Arenicola* sp.	Lugworm	12	30	4
23		*Nereis virens*	Clam worm	15	26	5
			Mollusca			
24	Cephalopoda	*Sepia officinalis*	Cuttlefish	15	320	19
25	Bivalvia	*Mytilus* sp.	Mussel	20	22	15
26	Gastropoda	*Aplysia limacina*	Sea hare	16	30	7
27		*Helix pomatia*	Land snail	20	94	26
28		*Lymnaea stagnalis*	Freshwater snail	20; 10	123; 36.7	28
			Aschelminthes			
29	Nematoda	*Ascaris lumbricoides*	Large roundworm	37	72[6]; 156[7]	14
30				37	♂112; ♀61	1
31		*Setaria equinum*	Filarial worm	38	250	23
			Platyhelminthes			
32	Cestoda	*Diphyllobothrium latum*	Fish tapeworm	37	243[8]	11
33	Trematoda	*Fasciola hepatica*	Liver fluke	37.5	330	24
34	Turbellaria	*Planaria torva*	Flatworm	25; 2.5	75.8; 18.9	27
			Cnidaria			
35	Anthozoa	*Anemonia sulcata*	Sea anemone	18	13.4	29
36	Scyphozoa	*Aurelia aurita*	Scyphomedusa	17; 31	5.0; 3.4	22

/1/ Subphylum. /2/ Baltic Sea. /3/ North Sea. /4/ Resting. /5/ True flight. /6/ Large. /7/ Small. /8/ Proglottids.

Contributor: Flemister, Launce J.

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continued

75. OXYGEN CONSUMPTION

Part III. INVERTEBRATES OTHER THAN PROTOZOA

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Part IV. PROTOZOA

Values are cubic millimeters oxygen per million cells per hour for mature protozoa.

	Class	Species	Temp., °C	Rate	Reference
	(A)	(B)	(C)	(D)	(E)
1	Ciliata	*Paramecium aurelia*[1]	35	1,512	4
2			30	831	
3			25	616	
4			20	354	
5	Sporozoa	*Plasmodium cathemerium*	38	0.25	1
6	Rhizopoda	*Amoeba chaos chaos*[2]	35	17,749	3
7			30	13,244	
8			25	9,010	
9			20	7,050	
10			15	5,040	
11	Mastigophora	*Trypanosoma gambiense*	37	1.70	5
12			30	0.38	
13		*Chilomonas paramecium*[3]	25	16.4	2

/1/ No substrate. /2/ Fed. /3/ Bacteria-free.

Contributor: Flemister, Launce J.

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76. RESPIRATION RATES

Part I. BACTERIA

Rate and degree of respiration may be affected by numerous factors, such as strain characteristics, composition of growth medium, age and number of cells in an inoculum, origin of inoculum, ages of culture harvested for study, nature of solution used for washing, number of washings, and composition of the respiratory system. Data are for bacterial suspensions in the presence of glucose.

	Species	Temp. °C	Culture Age hr	Q_{O_2} µl/mg dry wt/hr	Reference
	(A)	(B)	(C)	(D)	(E)
1	*Aerobacter aerogenes*	36; 30	17; 48	47; 50	1,2
2	*Azotobacter chroococcum*	22	36	2,000-10,000	9
3	*Bacillus subtilis*	37	6-8	170	6
4	*B. subtilis* (spores)	32	98-147	10	4
5	*Corynebacterium* sp.	30	48-96	67	8
6	*Escherichia coli*	40; 32	20	200; 272	1,7
7	*Lactobacillus bulgaricus*	45; 37	8	55; 34	14
8	*Micrococcus luteus*	35	30-34	15	10
9	*Mycobacterium avium*	37	84	1	11
10	*M. tuberculosis*	38	252	4	5
11	*Pseudomonas fluorescens*	26	20	58	12
12	*Streptococcus pyogenes*, C 203 M	37.5	4	57-163	13
13	*S. pyogenes*, C 203 S	37.5	4	99-113	13
14	*Streptomyces coelicolor*	......	72	35	3

Contributor: Silverman, Milton

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Part II. MYXOPHYTA AND FUNGI

Method (column D): Mano = manometric; Chem = chemical; Volu = volumetric. **Substrate** (column E): Endo = endogenous; CHO = carbohydrates; Org = organic compounds. Q_{CO_2} (column H): Values *not* in parentheses are for aerobic CO_2 production, those in parentheses are for anaerobic CO_2 production.

	Species	Material	Temp. °C	Method	Substrate	Specification	Respiration Rate µl/mg dry wt/hr[1] Q_{O_2}	Respiration Rate µl/mg dry wt/hr[1] Q_{CO_2}	Respiratory Quotient CO_2/O_2	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Myxomycetes									
1	*Physarum polycephalum*	Plasmodium	22	Mano	Endo	50 mg/vessel	1.4[2]	1.0[2] (0.24[2])	0.75-0.85	2
	Phycomycetes									
2	*Phycomyces blakesleeanus*	Mycelia	20	Chem	CHO	1.5; 3.5; 7 da	....	27; 13; 3	....	14
3	*Rhizopus sexualis*	Mycelia	20	Chem	Org	52 hr	....	25.7[3]	....	6
	Ascomycetes									
4	*Neurospora crassa*	Mycelia	30	Mano	Org	Endogenous	11-38	(0-5)	....	13
5	*Saccharomyces cerevisiae* R	Cell suspension	.....	Mano	CHO	No stored reserves	83-109	370-432 (278-299)	....	7

/1/ Unless otherwise indicated. /2/ µl per mg wet weight per hour. /3/ mg per g dry weight per hour.

continued

76. RESPIRATION RATES

Part II. MYXOPHYTA AND FUNGI

	Species	Material	Temp. °C	Method	Sub-strate	Specification	Respiration Rate µl/mg dry wt/hr[1] Q_{O_2}	Respiration Rate µl/mg dry wt/hr[1] Q_{CO_2}	Respiratory Quotient CO_2/O_2	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Ascomycetes									
6	*Saccharomyces cerevisiae* R	Cell suspension	.....	Mano	CHO	Fat reserves	76	249 (322)	....	7
7			.....	Mano	CHO	Glycogen reserves	0	63 (116)	....	
8	*S. cerevisiae* U	Cell suspension	.....	Mano	CHO	No stored reserves	10-137	160-348 (276-284)	....	7
9			.....	Mano	CHO	Fat reserves	125	151 (261)	....	
10			.....	Mano	CHO	Glycogen reserves	47	82 (83)	....	
11	*Schizosaccharomyces octosporus*	Cell suspension	30	Mano	CHO	Endogenous; + glucose	21; 90	(0.1)	....	12
	Basidiomycetes									
12	*Agaricus campestris*	Growing culture	25	Volu	....	....	1.9-2.9	2.3-4.0	0.70-0.90	4
13	*Puccinia graminis*	Urediospore	30	Mano	Endo	PO_4 buffer, pH 6.5, ungerminated	1.6[2]	1.1[2]	0.65	10
14			30	Mano	Endo	Germinated	1.4[2]	1.0[2]	0.70	
15	*Ustilago sphaerogena*	Sporidia[4]	.....	Mano	Endo	....	75	....	....	1
16			.....	Mano	CHO	+ Sugars	375	....	....	
	Fungi Imperfecti									
17	*Alternaria* sp.	Pellets	23-25	Chem	CHO	....	....	....	1.26-1.31	3
18	*Aspergillus niger*	Mycelia	35; 19	Chem	CHO	+ Glucose	......	....	1.30; 0.98	9
19			35; 18	Chem	CHO	+ Sucrose	......	....	1.22; 0.91	
20			36	Chem	Org	+ Tartrate	......	....	1.35-2.03	
21			36	Chem	Org	+ Glycerol	......	....	0.82-0.86	
22	*Candida albicans*	Cell suspension[5]	30	Mano	Endo	....	5	....	....	8
23			30	Mano	CHO	+ Glucose	40	....	....	
24	*Cladosporium* spp.	Pellets	23-25	Chem	CHO	5 strains	.....	....	1.10-1.28	3
25	*Fusarium trichothecioides*	Mycelia[6] (1 da old)	30	Mano	Endo	1; 4 hr	40; 13	31; 11	0.78; 0.84	5
26			30	Mano	CHO	1; 4 hr (+ glucose)	34; 39	64; 56	1.85; 1.55	
27		Mycelia[6] (3 da old)	30	Mano	Endo	1; 4 hr	14; 13	14; 12	1.01; 0.92	
28			30	Mano	CHO	1; 4 hr (+ glucose)	14; 13	19; 26	1.36; 1.97	
29	*Helminthosporium gramineum*	Pellets	23-25	Chem	CHO	....	......	....	1.31	3
30	*Penicillium notatum*	Mycelia[5]	20-24	Mano	Endo	0; 1 da	6.5; 1.7	....	....	15
31		Mycelia	20-24	Mano	CHO	2; 4; 7 da	6; 16; 2	....	....	
32	*Torulopsis utilis*	Cell suspension	30	Mano	Endo	+ Glycine	3.7[2]	....	0.86	11
33			30	Mano	Endo	+ Urea	3.5[2]	....	1.15	
34			30	Mano	Endo	+ α-Alanine	5.2[2]	....	0.89	
35			30	Mano	Endo	+ β-Alanine	4.2[2]	....	1.16	

/1/ Unless otherwise indicated. /2/ µl per mg wet weight per hour. /4/ Washed. /5/ Starved. /6/ Homogenized.

Contributors: (a) Darb , Richard T., and Mandels, Gabriel R., (b) Henderson, Lavaniel L., Sr.

References: [1] Allen, P. J. 1948. Am. J. Botany 35:799. [2] Allen, P. J., and W. H. Price. 1950. Ibid. 37:393. [3] Birkinshaw, J. H., et al. 1931. Phil. Trans. Roy. Soc. London, B, 220:99. [4] Chevillard, L., A. Meyer, and L. Plantefol. 1930. Ann. Physiol. Physicochim. Biol. 6:506. [5] Gould, B. S., and A. A. Tytell. 1941. J. Gen. Physiol. 24:655. [6] Hawker, L. E., and P. M. Hepden. 1962. Ann. Botany (London) 26:619. [7] Lindegren, C. C. 1946. Arch. Biochem. Biophys. 9:353. [8] Nickerson, W. J. 1946. Am. J. Botany 33:831. [9] Porievitch, K. 1905. Ann. Sci. Nat. Botan. Biol. Vegetale, Ser. 9, 1:1. [10] Shu, P., K. G. Tanner, and G. A. Ledingham. 1954. Can. J. Botany 32:16. [11] Sperber, E. 1945. Arkiv Kemi 21A(3):1. [12] Spiegelman, S., and M. Nozawa. 1945. Arch. Biochem. Biophys. 6:303. [13] Strauss, B. S. 1952. Ibid. 36:33. [14] Wassink, E. C. 1934. Rec. Trav. Botan. Neerl. 31:583. [15] Wolf, F. T. 1947. Arch. Biochem. Biophys. 13:83.

continued

76. RESPIRATION RATES

Part III. LICHENS, ALGAE, AND BRYOPHYTES

Method (column C): Mano = manometric; Cond = conductometric; Chem = chemical. Figures in parentheses are control or endogenous values.

	Division or Class, and Species	Temp. °C	Method	Respiration Rate µl/100 mg dry wt/hr[1]		Respiratory Quotient CO_2/O_2	Reference
				Q_{O_2}	Q_{CO_2}		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Lichenes						
	Ascolichenes						
1	*Alectoria nigricans*	30; 10; 0	Mano	33; 14; 8	....	....	16
2	*Cladonia sylvatica*	30; 10; 0	Mano	24; 6.8; 2.9	....	....	16
3	*Parmelia nigrociliata*	30; 10; 0	Mano	25; 13; 4	....	....	16
4	*Peltigera aphthosa*	30; 10; 0	Mano	90; 33; 17	....	....	16
5	*Umbilicaria proboscidea*	30; 10; 0	Mano	18; 6.5; 3.5	....	....	16
6	*Usnea dasypoga*	....	Cond	....	60-90[2]	....	15
	Algae						
	Cyanophyta						
7	*Anabaena variabilis*[3]	25	Mano	170 (840)	....	1.0 (1.1)	14
8	*Anacystis nidulans*[3]	39; 25	Mano	200 (500); 30 (160)	....	1.1 (1.1); 0.9 (1.0)	14
9	*Nostoc muscorum*[3]	25	Mano	110 (440)	....	....	14
	Chlorophyta						
10	*Chlorella pyrenoidosa*	20	Mano	1,700	....	1.39	7
11		18; 3.5	Mano	890 (430); 200 (150)	....	(0.94); (0.98)	6
12	*Cladophora rupestris*	20	Chem	33	....	....	8
13	*Spirogyra majuscula*[4]	10.4	Chem	0.5[5]	....	....	3
14	*Ulothrix flacca*	....	Chem	160	....	....	9
	Phaeophyta						
15	*Ectocarpus siliculosus*	12	Chem	41[5]	....	....	10
16	*Fucus vesiculosus*	14	Chem	....	12.7[6]	....	2
17	*Laminaria digitata*	5	Mano	....	0.9[7]	0.67	13
	Rhodophyta						
18	*Polysiphonia violacea*	11	Chem	....	107	1.02	10
19	*Porphyra laciniata*	17	Chem	39	....	....	12
	Bryophyta						
	Musci						
20	*Hylocomium squarrosum*	30; 20; 5	Chem	....	100; 61; 15	....	17
21	*Hypnum cupressiforme*	18.5	Chem	2-30[2]	....	....	5
22	*Mnium undulatum*	....	......	....	7.5-97.0[2]	....	11
23	*Polytrichum juniperinum*[8]	18	......	....	1.2[5]-0.7[5]	1.00-0.65	1
24	*Sphagnum girgensohnii*	30; 20; 5	Chem	....	130; 71; 20	....	17
	Hepaticae						
25	*Marchantia polymorpha*	20	Chem	....	0.6[7]	....	4
26	*Riccia fluitans*	25	Mano	250-300	....	....	18

/1/ Unless otherwise indicated. /2/ Effect of moisture. /3/ After 24-hour dark starvation. /4/ Effect of pH. /5/ µl per 100 mg wet weight per hour. /6/ µg per 100 g wet weight per hour. /7/ µl per sq cm per hour. /8/ Shoots or tops only; values show change caused by growth, development, or maturation.

Contributors: (a) Mandels, Gabriel R., and Darby, Richard T., (b) Myers, Jack, (c) Henderson, Lavaniel L., Sr.

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continued

76. RESPIRATION RATES

Part IV. TRACHEOPHYTA

Method (column E): Mano = manometric; Chem = chemical; Cond = conductometric. Figures in parentheses are control or endogenous values.

	Species	Common Name	Condition or Part	Temp. °C	Method	Respiration Rate µl/100 mg wet wt/hr[1] Q_{O_2}	Respiration Rate µl/100 mg wet wt/hr[1] Q_{CO_2}	Respiratory Quotient CO_2/O_2	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
					Seeds				
1	*Acer saccharum*	Sugar maple	Resting	...	...	...	14	...	42
2	*Avena sativa*[2]	Common oat	Coleoptile, segment	30	Mano	47-39	...	...	12
3	*Cucurbita pepo*	Pumpkin	Germinating	25	Chem	...	10-117	0.94-0.62	49
4	*Fagopyrum esculentum*	Buckwheat	Germinating	25	...	...	41-306	0.8-1.0	48
5	*Glycine soja*[3]	Soybean	Germinating	...	Mano	...	...	0.93-0.87	24
6	*Gossypium hirsutum*[4,5]	Upland cotton	Resting	26	Mano	...	0.03-6.0	0.96-1.12	43
7	*Helianthus annuus*	Common sunflower	Resting	28	Mano	...	...	1.05	67
8			Germinating	25	Chem	...	41-407	0.85-0.50	49
9	*Hordeum vulgare*[4]	Barley	Resting	37.8	Chem	...	0.002[6]-0.36[6]	...	7
10	*Juglans regia*	Persian walnut	Resting	28	Mano	...	...	0.52	67
11	*Juniperus virginiana*	Eastern red cedar	Resting	25	Mano	...	0.05	0.76	63
12			Germinating	25	Mano	...	6.6-25	0.84-0.97	63
13	*Malus pumila*	Common apple	Resting	19	...	...	2.8[6]	0.86	35
14	*Medicago sativa*	Alfalfa	Resting	18	Mano	38	...	1.08	30
15			Germinating	18	Mano	106	...	0.86	30
16	*Oryza sativa*	Rice	Resting	...	Mano	0.03[6]	...	1.15	25
17			Moist	...	Mano	2.8[6]	...	1.96	25
18			Germinating	...	Mano	4.9[6]	...	1.98	25
19			Seedling	...	Mano	1.06[6]	...	1.00	25
20	*Phaseolus vulgaris*	Kidney bean	Germinating	...	...	...	65	...	50
21	*Pinus radiata*	Monterey pine	Resting	...	Mano	...	0.0013[6]	...	84
22	*Pisum sativum*	Garden pea	Resting	28	Mano	...	...	1.00	67
23	*P. sativum*[7]	Garden pea	Intact	20	Chem	...	15 (35)	4.9 (1.1)	65
24	*Prunus amygdalus*[3]	Almond	Germinating	...	Mano	...	...	0.7-0.86	24
25	*P. domestica*	Garden plum	Moist	25	Mano	4.7	...	0.91	72
26	*P. persica*	Peach	Moist	25	Mano	5.8	...	0.68	72
27	*Raphanus sativus*	Garden radish	Resting	20	Mano	7.0	...	0.86	30
28			Germinating	20	Mano	1.03	...	0.58	30
29	*Triticum aestivum*[4]	Wheat	Resting	38	Chem	...	0.005[6]-0.16[6]	...	8
30	*T. aestivum*[4]	Wheat	Germinating	38	Chem	...	0.014[6]-0.53[6]	...	8
31	*T. aestivum*	Wheat	Seedling	18	Chem	...	21	...	76
32	*Vicia faba*	Broad bean	Resting	28	Mano	...	...	0.99	67
33			Germinating	25	Chem	...	...	1.23-0.82	78
34			Seedling	20	Chem	...	13	...	76
35	*Zea mays*[4]	Corn	Resting	22	Chem	...	0.24[6]-1.2[6]	...	2
36	*Z. mays*	Corn	Germinating	25	...	...	10-127	0.75-1.0	48
37	*Z. mays*	Corn	Seedling	18	Chem	15	...	...	76
					Roots				
38	*Allium cepa*[3]	Garden onion	Segment	25	Mano	1,390[6]-1,140[6]	...	0.99-1.07	10
39	*Beta vulgaris*[5,7]	Beet	Intact	25	Chem	...	0.9-0.6	0.8	17
40	*B. vulgaris*[5]	Beet	Segment	25	Mano	70[6]-180[6]-110[6]	...	1.01-0.85	77
41	*Chrysanthemum morifolium*	Florist's chrysanthemum	Intact	28	Mano	...	...	0.93	67
42	*Daucus carota*[5]	Carrot	Intact	24	Chem	...	3.3-1.5	1.10-1.18	64
43			Intact	10	Chem	...	1.5-0.5	1.08-1.01	64
44			Intact	0.5	Chem	...	0.44-0.22	0.92-1.16	64
45	*Glycine soja*	Soybean	Nodule	28	Mano	60[6]-430[6]	...	1.0-2.0	1
46	*Gossypium herbaceum*[3]	Levant cotton	Intact	38	Chem	...	380[6]-73[6]	...	38
47	*Hordeum vulgare*[7]	Barley	Intact	20	Cond	...	484[6]-740[6]	...	86
48	*Ipomoea batatas*	Sweet potato	Intact	35	Chem	...	5.6-6.2	...	41

/1/ Unless otherwise indicated. /2/ Effect of substrate. /3/ Effect of growth, development, or maturation. /4/ Effect of moisture. /5/ Effect of storage or starvation. /6/ µl per 100 mg dry weight per hour. /7/ Effect of oxygen.

continued

76. RESPIRATION RATES

Part IV. TRACHEOPHYTA

	Species	Common Name	Condition or Part	Temp. °C	Method	Respiration Rate µl/100 mg wet wt/hr[1] Q_{O_2}	Q_{CO_2}	Respiratory Quotient CO_2/O_2	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
				Roots					
49	*Ipomoea batatas*	Sweet potato	Intact	25	Chem	...	3.2-4.0	...	41
50			Intact	15	Chem	...	1.4-1.9	...	41
51			Segment	25	Mano	96	...	1.0	81
52	*Lycopersicon esculentum*	Tomato	Excised	25	Mano	600[6]-800[6]	...	1.0	37
53	*Malus pumila*	Common apple	Intact	14	Chem	...	26[6]	0.73	83
54	*Oryza sativa*[3]	Rice	Intact	15-18	...	180[6]-230[6]	...	...	46
55	*Pastinaca sativa*	Parsnip	Intact	22; 1.5	Chem	...	2.7; 1.1	...	2
56	*Raphanus sativus*	Garden radish	Intact	28	Mano	...	...	0.99	67
57	*Triticum aestivum*[8]	Wheat	Intact	20	Chem	25[6] (10[6])	...	...	51
58	*Vicia faba*	Broad bean	Excised	26	Mano	...	...	1.46	69
				Stems					
59	*Acer rubrum*[3]	Red maple	Xylem	25	Mano	3.7-2.3	...	...	31
60			Cambium	25	Mano	22.4	...	...	31
61			Phloem	25	Mano	16.9	...	...	31
62	*Asparagus officinalis*[5]	Garden asparagus	Shoot	30	Chem	...	915[6]-254[6]	...	9
63			Intact	24	Chem	...	35.4-13.2	1.04-0.95	64
64			Intact	10	Chem	...	9.7-3.6	1.03-0.86	64
65			Intact	0.5	Chem	...	3.0-2.0	0.98-0.95	64
66	*Elodea canadensis*	Canada waterweed	Shoot	20	Mano	90[6]	...	...	29
67	*Equisetum telmateia*	Giant horsetail	Shoot or top	20	Mano	...	6	0.78	52
68			Fruiting shoot or top	20	Mano	...	100	0.83	52
69			Intact	Room	Mano	...	9.6	0.80	57
70			Branchlet	Room	Mano	...	19	0.69	57
71	*Fraxinus nigra*[3]	Black ash	Xylem	25	Ma	...	31.3-1.4	...	31
72			Phloem	25	Ma	...	16.7	...	31
73			Cambium	25	Mano	...	22	...	31
74	*Gladiolus* sp.	Gladiolus	Corm	23	Chem	...	8.5[6]	...	21
75	*Gossypium herbaceum*[3]	Levant cotton	Intact	38	Chem	...	168[6]-42[6]	...	38
76	*Helianthus annuus*	Common sunflower	Shoot	25;10;5	Chem	...	483[6];141[6];76[6]	...	44
77	*Ipomoea batatas*[5]	Sweet potato	Tuber	30	Chem	...	1.4-7.0-2.4	...	36
78	*Lycopersicon esculentum*[8]	Tomato	Segment	28	Mano	420[6]-350[6]	...	0.91-0.95	44
79	*Malus pumila*[9]	Common apple	Intact	6	Chem	...	1.2-4.6	...	20
80	*Nicotiana glauca* x *N. langsdorffi*[10,11]	Tobacco	Callus	30	Mano	380[6]	...	1.0	56
81	*Phaseolus vulgaris*[11,12]	Kidney bean	Intact	30	Mano	28[6]-710[6]	...	0.9-1.1	74
82	*P. vulgaris*[12]	Kidney bean	Shoot	24	Chem	...	190[6] (150[6])	...	16
83	*Pisum sativum*[5]	Garden pea	Segment	25	Mano	334[6] (532[6])	...	0.98 (1.07)	18
84	*Prunus laurocerasus*[5]	Laurel cherry	Shoot	22.5	Chem	...	14.4-2.6	...	6
85	*Quercus coccifera*[3]	Kermes oak	Segment	21	Mano	...	31-11	0.91-0.83	58
86	*Raphanus raphanistrum*	Wild radish	Intact	Room	Mano	...	10.5	0.87	57
87	*Salix herbacea*	Pygmy willow	Shoot	20;10;0	Chem	...	23.4;9.1;2.5	...	80
88	*Solanum tuberosum*[5]	Potato	Tuber	24	Chem	...	0.6-0.3	1.02-0.75	64
89			Tuber	10	Chem	...	0.2-0.15	0.86-0.99	64
90			Tuber	0.5	Chem	...	0.07-0.15	0.45-0.66	64
91	*Taxus baccata*	English yew	Shoot	28	Mano	...	...	0.97	67
92	*Triticum aestivum*	Wheat	Shoot	13; 8	Mano	...	29; 19	0.98; 1.03	4

/1/ Unless otherwise indicated. /3/ Effect of growth, development, or maturation. /5/ Effect of storage or starvation. /6/ µl per 100 mg dry weight per hour. /8/ Effect of inorganic nutrition, salts. /9/ Effect of precooling. /10/ Effect of pH. /11/ Effect of metabolic poisons. /12/ Effect of herbicides.

continued

76. RESPIRATION RATES

Part IV. TRACHEOPHYTA

	Species	Common Name	Condition or Part	Temp. °C	Method	Respiration Rate µl/100 mg wet wt/hr[1] Q_{O_2}	Respiration Rate µl/100 mg wet wt/hr[1] Q_{CO_2}	Respiratory Quotient CO_2/O_2	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
	Stems								
93	*Vicia faba*	Broad bean	Intact	Room	Mano	...	6.2	...	57
94			Shoot	21	Mano	...	62.6	0.90	57
95			Shoot	21	Mano	...	48.8	0.87	57
96	*Zea mays*[13]	Corn	Shoot	30	Mano	...	760[6]	...	32
	Leaves								
97	*Acer pseudoplatanus*	Plane-tree maple	Intact	10	Chem	...	33	...	66
98	*Allium cepa*	Garden onion	Bulb	22	Chem	...	2.1	...	2
99	*Antirrhinum majus*	Snapdragon	Intact	20	Mano	...	16	0.88	52
100	*Asparagus albus*	White asparagus	Tendril, phyllode, or cladode	Room	Mano	...	22.3	0.78	57
101	*Beta vulgaris*	Beet	Intact	27	Chem	...	23	...	53
102	*Betula nana*	Dwarf arctic birch	Intact	20; 10	Chem	...	66; 26	...	80
103	*Catalpa bignonioides*	Southern catalpa	Intact	14	Chem	...	18-25	...	66
104	*Citrus limon*	Lemon	Intact	...	Mano	7.7[14]-9.5[14]	...	...	82
105	*C. sinensis*	Sweet orange	Intact	...	Mano	9.6[14]-12.9[14]	...	...	82
106	*Elodea canadensis*	Canadà waterweed	Intact	...	Mano, Chem	...	...	8.4	68
107	*Fagus sylvatica*	European beech	Intact	20	Chem	...	1[14]-5[14]	...	14
108	*Fragaria* sp.[3]	Strawberry	Intact	24.5	Chem	...	10[14]-5[14]	...	3
109	*Fraxinus excelsior*[13]	European ash	Intact	20	Chem	...	1[14]-6[14]	...	14
110	*Gladiolus gandavensis*	Breeder's gladiolus	Intact	24	Mano	...	18	0.64	52
111	*Gossypium herbaceum*[3]	Levant cotton	Intact	38	Chem	...	224[6]-94[6]	...	38
112	*Helianthus annuus*[5]	Common sunflower	Intact	25	Chem	...	9[14]-3[14]	...	75
113	*Hordeum vulgare*[5]	Barley	Intact	25	Chem	...	76-15	1.2-0.8	87
114	*Ilex aquifolium*	English holly	Intact	21	Mano	...	12	...	76
115	*Ipomoea grandiflora*	Large moonflower	Intact	20	Mano	220[6]	...	...	29
116	*Iris germanica*[5]	German iris	Intact	22.5	Chem	...	12-13.6-5	...	5
117	*Lactuca sativa*[5]	Lettuce	Intact	24	Chem	...	3.3-2.6	1.12-0.99	63
118			Intact	10	Chem	...	1.3-0.73	1.09-0.93	63
119			Intact	0.5	Chem	...	0.8-0.35	0.84-0.98	63
120	*Lycopersicon esculentum*[13]	Tomato	Intact	27	Mano	260[6]-320[6]	...	...	23
121	*L. esculentum*[8]	Tomato	Segment	30	Mano	46 (42)	...	1.13 (1.28)	79
122	*L. esculentum*[8]	Tomato	Segment	28	Mano	390[6]-430[6]	0.96-0.91	...	45
123	*Malus pumila*[4]	Common apple	Intact	33	Chem	...	8.6[14]-43.0[14]	...	70
124	*Nicotiana glauca* x *N. langsdorffi*[3]	Tobacco	Segment	25	Mano	330[6]-170[6]	...	1.27-1.43	56
125	*Oenothera biennis*[3]	Common evening primrose	Blade	18	Mano	...	24-12	0.83-0.70	58
126	*Phaseolus vulgaris*	Kidney bean	Intact	26	Mano	26-57	...	...	40
127	*Phleum pratense*	Timothy	Intact	21-26	...	124[6]	...	...	46
128	*Phoenix dactylifera*	Date palm	Intact	20	Chem	...	4.5[14]	...	28
129	*Pinus pinea*	Italian stone pine	Intact	24; 14	Mano	...	12; 6.9	0.83; 0.82	13
130	*Pisum sativum*[13]	Garden pea	Intact	27	Mano	430[6]-680[6]	...	...	23

/1/ Unless otherwise indicated. /3/ Effect of growth, development, or maturation. /4/ Effect of moisture. /5/ Effect of storage or starvation. /6/ µl per 100 mg dry weight per hour. /8/ Effect of inorganic nutrition, salts. /13/ Effect of light or photoperiod. /14/ µl per sq cm per hour.

continued

76. RESPIRATION RATES

Part IV. TRACHEOPHYTA

	Species	Common Name	Condition or Part	Temp. °C	Method	Respiration Rate µl/100 mg wet wt/hr[1] Q_{O_2}	Q_{CO_2}	Respiratory Quotient CO_2/O_2	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
	Leaves								
131	*Polypodium vulgare*	Common polypody	Frond	20	Mano	...	10	0.92	52
132			Frond with sori	20	Mano	...	19	1.06	52
133	*Populus deltoides* x *P. nigra*	Poplar	Intact	...	Chem	...	19	...	66
134	*Prunus amygdalus*	Almond	Intact	14	Mano	...	29	1.00	59
135	*P. laurocerasus*[5]	Laurel cherry	Intact	22.5	Chem	...	20-3.4-13.6	...	6
136	*Quercus coccifera*[3]	Kermes oak	Intact	21	Mano	...	44-13	0.87-0.79	58
137	*Raphanus raphanistrum*	Wild radish	Blade	Room	Mano	...	13.3	0.73	57
138			Petiole	Room	Mano	...	6.2	0.86	57
139	*Rheum rhaponticum*	Garden rhubarb	Segment	30	Mano	...	29	1.17	55
140	*Rhododendron fargesi*[5]	Père Farges' rhododendron	Intact	22.5	Chem	...	13.6-5.1	...	5
141	*Rosa* sp.	Rose	Intact	14	Mano	...	23	0.93	59
142	*Salix glauca*	Gray-leaf willow	Intact	20;10;0	Chem	...	78;45;13	...	80
143	*Solanum tuberosum*	Potato	Intact	48;30	Chem	...	137;41	...	39
144			Intact	10	Chem	10	...	...	39
145	*Taxus baccata*	English yew	Intact	46;34;16	Mano	...	55;23;6	0.89;0.80;0.86	13
146	*Tradescantia viridis*	Wandering Jew	Intact	29	Mano	...	...	1.01	67
147	*Triticum aestivum*	Wheat	Intact	25	Mano	...	40.2	0.97	57
148			Intact, etiolated	25	Mano	...	37.5	0.98	57
149	*Ulmus glabra*	Scotch elm	Intact	16	Chem	...	24	...	66
150	*Vicia faba*	Broad bean	Blade	Room	Mano	...	11.1	...	57
151			Petiole	Room	Mano	...	4.1	...	57
152	*Vitis vinifera*	European grape	Blade	...	Chem	...	81[6]	...	54
153	*Yucca gloriosa*[5]	Mound lily yucca	Intact	22.5	Chem	...	8.5-3.3	...	5
154	*Zea mays*	Corn	Intact	26	Mano	...	68.3	0.99	57
155			Intact, etiolated	26	Mano	...	54.1	0.97	57
	Flowers								
156	*Antirrhinum majus*[3]	Snapdragon	Petal	23	Mano	...	82-70-34	1.15-1.13-1.00	52
157			Stamen	24	Mano	...	81-106-76	...	52
158	*Cucumis sativus*[3]	Cucumber	Pistil	22	Mano	...	48-43-29	...	52
159	*Gladiolus gandavensis*	Breeder's gladiolus	Petal	24	Mano	...	15	0.72	52
160			Stamen	24	Mano	...	27	0.77	52
161			Pistil	24	Mano	...	71	0.90	52
162	*Helianthus annuus*[3]	Common sunflower	Inflorescence	10	Chem	...	57[6]-43[6]	...	44
163	*Lilium bulbiferum*[3]	Bulbil lily	Stamen	...	...	...	56-21	1.14-0.98	33
164			Pistil	...	...	...	58-19	1.06-1.12	33
165	*Pinus densiflora*	Japanese red pine	Pollen	25	Mano	160[6]	...	...	60, 61
166	*Rosa* sp.	Rose	Intact	28	Mano	...	...	1.04	52
167	*Yucca gloriosa*[3]	Mound lily yucca	Pistil	16	Mano	...	24-23-22	...	52
168			Petal	24	Mano	...	67-41-44	0.91-0.97-1.07	52
	Fruits								
169	*Capsicum frutescens*[5]	Bush red pepper	Intact	24	Chem	...	4.0-1.4	1.12-0.88	64
170			Intact	10	Chem	...	1.2-0.58	1.27-0.88	64
171			Intact	0.5	Chem	...	0.44-0.29	0.96	64
172	*Citrus limon*	Lemon	Intact	38;21;0	...	...	4.1;1.1;0.15	1.4;1.0;1.2	34

/1/ Unless otherwise indicated. /3/ Effect of growth, development, or maturation. /5/ Effect of storage or starvation. /6/ µl per 100 mg dry weight per hour.

continued

Part IV. TRACHEOPHYTA

	Species	Common Name	Condition or Part	Temp. °C	Method	Respiration Rate µl/100 mg wet wt/hr[1] QO_2	QCO_2	Respiratory Quotient CO_2/O_2	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
				Fruits					
173	*Citrus sinensis*	Sweet orange	Intact	21;10;0	....	....	2.0;0.8;0.15	1.1;1.1;1.2	34
174	*Cucumis sativus*[5]	Cucumber	Intact	24	Chem	....	2.3-0.8	1.01-0.91	64
175			Intact	10	Chem	....	1.0-0.4	1.01-1.10	64
176			Intact	0.5	Chem	....	0.2-0.08	0.97-0.88	64
177	*Fragaria* sp.[3]	Strawberry	Intact	20	Chem	....	3.3-5.1	0.84-0.91	62
178	*Helianthus annuus*	Common sunflower	Intact	25	Mano	....	....	0.96	67
179	*Lycopersicon esculentum*[5]	Tomato	Intact	24	Chem	....	2.5-1.6	1.11-1.13	64
180			Intact	10	Chem	....	0.77-0.58	1.39-1.06	64
181			Intact	0.5	Chem	....	0.36-0.15	1.11-0.9	64
182	*Malus pumila*[3]	Common apple	Intact	27	Mano	....	2.4-5.1-0.6	0.43-0.91	71
183			Intact	20	Chem	....	1.7-0.8	....	27
184	*Nicotiana tabacum*	Common tobacco	Intact	28	Mano	....	....	0.94	67
185	*Persea americana*[5]	American avocado	Intact	15	Chem	....	5.8-3.6-8.1	....	11
186	*Phaseolus vulgaris*[5]	Kidney bean	Intact	24	Chem	....	16.4-6.6	1.14-1.00	64
187			Intact	10	Chem	....	4.6-2.0	1.08-0.98	64
188			Intact	0.5	Chem	....	0.95-0.65	0.94-0.96	64
189	*Pisum sativum*[5]	Garden pea	Intact	24	Chem	....	20-12	1.32-1.06	64
190			Intact	10	Chem	....	7.9-3.1	1.13-1.00	64
191			Intact	0.5	Chem	....	2.2-1.4	1.07-0.96	64
192	*Prunus domestica*[5]	Garden plum	Intact	18	Chem	....	1.7-3.6	....	19
193	*P. domestica*	Garden plum	Intact	4	Chem	....	0.5	....	19
194	*P. persica*[5]	Peach	Intact	18	Chem	....	4-2.0	....	19
195			Intact	4	Chem	....	0.4-0.3	....	19
196	*Pyrus communis*[3]	Pear	Intact	18	Chem	....	6.3-1.0-1.2	....	26
197	*Quercus alba*	White oak	Intact	30;10;2.5	Mano	21[6];16[6];17[6]	....	0.71;0.30;0.16	15
198	*Ribes rubrum*	Northern red currant	Intact	28	Mano	....	....	1.4	67
199	*Rosa* sp.	Rose	Intact	28	Mano	....	....	0.86	67
200	*Solanum lycopersicum*	Nightshade	Intact	28	Mano	....	....	1.9	67
201	*Triticum aestivum*[3]	Wheat	Intact	28	Mano	340[6]-8[6]	....	....	73
202	*Vitis vinifera*	European grape	Intact	28	Mano	....	....	1.6	67
203	*Zea mays*	Corn	Intact	28;4.5	Chem	....	17-11;3.5	....	2
				Whole Plants					
204	*Betula nana*	Dwarf arctic birch	Intact	16	Mano	....	7.0[14]	0.93	47
205	*Gossypium herbaceum*[3]	Levant cotton	Intact	38	Chem	....	198[6]-65[6]	....	38
206	*Helianthus annuus*[3]	Common sunflower	Intact	10	Chem	....	148[6]-13[6]	....	44
207	*Ipomoea batatas*[15]	Sweet potato	Intact	21	Mano	....	1-2	....	85
208	*Triticum aestivum*[6]	Wheat	Intact	2	Chem	....	38[6]13[6]	....	22

/1/ Unless otherwise indicated. /3/ Effect of growth, development, or maturation. /5/ Effect of storage or starvation. /6/ µl per 100 mg dry weight per hour. /14/ µl per sq cm per hour. /15/ Effect of wounding.

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77. HEART RATES

Heart rate varies with species, sex, age, size, environment, and temperature. Values in parentheses are ranges, estimate "c" (cf. Introduction).

Part I. MAN

	Specification	Heart Rate beats/min	Reference
	(A)	(B)	(C)
	Embryo		1
1	5th mo	156(150-160)	
2	6th mo	154(141-155)	
3	7th mo	149(118-156)	
4	8th mo	142(129-152)	
5	9th mo	146(131-173)	
6	Premature	145(110-185)	6
7	Newborn	134(101-160)	5
8	1 yr	111(84-136)	5
9	2 yr	108(84-134)	5
10	4 yr	103(80-133)	5
11	5-9 yr	96(68-128)	3
12	10-14 yr	87(56-120)	3
13	15-19 yr	79(52-112)	3
14	20-24 yr	74(41-100)	3
15	25-30 yr	72(52-102)	5
16	30-35 yr	70(58-104)	5
17	35-40 yr	72(56-100)	5
18	40-45 yr	72(50-104)	5
19	45-50 yr	72(49-100)	5
20	50-55 yr	72(52-94)	5
21	55-60 yr	75(48-108)	5
22	60-65 yr	73(54-100)	5
23	65-70 yr	75(52-96)	5
24	70-75 yr	75(54-104)	5
25	75-80 yr	72(50-94)	5
26	>80 yr	77(63-98)	3
	College students, ♂		4
27	Basal	65(45-105)	
28	Recumbent	66(40-100)	
29	Sitting	73(48-105)	
30	Standing	82(54-124)	
	28 yr old, ♂		2
31	Sleeping	59.4(52.8-67.1)	
32	Awake	77.8(61.2-111.8)	
	25 yr old, ♀		2
33	Sleeping	65.3(5[illegible]7-75.4)	
34	Awake	83.9([illegible].1-120.6)	

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Part II. VERTEBRATES OTHER THAN MAN

Values are for adult animals, unless otherwise specified.

	Species	Common Name	Specification	Heart Rate beats/min	Reference
	(A)	(B)	(C)	(D)	(E)
		Mammalia			
1	*Bos taurus*	Cattle	500 kg; 38°C	46-53	2
2		Young	....	106(100-115)	19
3		Newborn	....	(141-160)	8
4		Embryo	....	161	8
5	*Camelus bactrianus*	Bactrian camel	....	(25-32)	19
6	*Canis familiaris*	Dog	5-20 kg	(72-200)	8,27,36
7		Young	1,040 g	208(145-275)/1/	18
8		Newborn	....	(160-180)	8
9		Embryo	....	(120-170)	8
10	*Capra hircus*	Goat	33 kg; 39°C	81(70-135)	2,8
11		Newborn	....	(145-240)	1
12		Embryo	....	(120-246)	1
13	*Cavia porcellus*	Guinea pig	300-750 g	(230-300)	8,20
14			437 g	269(225-312)/1/	18
15	*Dasypus novemcinctus*	Nine-banded armadillo	2.8-4.0 kg; 32-36°C	(70-100)	29
16	*Delphinapterus leucas*	Beluga whale	....	(15-16)	34
17	*Didelphis marsupialis virginiana*	Virginia opossum	2.2-3.2 kg; 35°C	187(140-228)/1/	10

/1/ Anesthetized.

continued

77. HEART RATES

Part II. VERTEBRATES OTHER THAN MAN

	Species	Common Name	Specification	Heart Rate beats/min	Reference
	(A)	(B)	(C)	(D)	(E)
		Mammalia			
18	*Elephas maximus*	Asiatic elephant	2,000-3,000 kg; 36°C	(25-50)	2,8,36
19	*Equus caballus*	Horse	380-450 kg	(34-55)	8,19
20		Young	....	63(60-71)	19
21		Newborn	....	(100-120)	26
22	*Erinaceus europaeus*	European hedgehog	500-900 g; 36°C	246(234-264)	10
23			485 g	263(200-325)[1]	18
24	*Eutamias minimus*	Least chipmunk	40 g; 38.7°C	684(660-702)	10
25	*Felis catus*	Cat	2.5 kg	(110-240)[1]	8,27
26		Young	117 g	300	8
27		Newborn	....	300	8,21
28	*Macaca irus*	Crab-eating macaque	....	215	11
29	*Mesocricetus auratus*	Golden hamster	103 g	347(276-[illegible]0)[1]	18
30			75-103 g	(375-425)	20
31	*Mus musculus*	House mouse	10-20 g; 38.4°C	624(480-738)[1]	10
32			17.4 g	500(450-550)[1]	17
33		Young	12 g	670	4,8
34	*Mustela vison*	Mink	0.7-1.4 kg; 40.5°C	(272-414)	10
35	*Myotis lucifugus*	Little brown bat	6 g	588[1]	10
36	*Ondatra zibethica*	Muskrat	0.8-1.3 kg; 38°C	(148-306)[1]	10
37	*Oryctolagus cuniculus*	European rabbit	1,344 g	251(167-330)[1]	18
38		Newborn	....	220	13
39	*Ovis aries*	Sheep	50 kg	(70-80)	30
40	*Phoca vitulina*	Harbor seal	20-25 kg	100	17
41	*Phocaena phocaena*	Harbor porpoise	170 kg	(40-110)	16
42	*Rattus norvegicus*	Norway rat	252 g	352(260-450)[1]	18
43			92-210 g	305(270-350)[2]	15
44		Newborn	....	161(121-201)	21
45		Embryo	....	(95-256)	1
46	*Sciurus carolinensis*	Gray squirrel	500-600 g; 40.1°C	390	10
47	*Sorex cinereus*	Gray shrew	3-4 g; 38.8°C	782(588-1,320)	22
48	*Sus scrofa*	Swine	100 kg	(60-80)	8,12,19
49		Newborn	....	227	21
		Aves			
50	*Anas platyrhynchos*	Mallard duck	2,304 g	212(133-268)	8,31
51	*Anser* sp.	Goose	4,000 g	80	8,23
52			2,800 g	144	8,33
53	*Archilochus colubris*	Ruby-throated hummingbird	4 g	615[2]	24
54	*Columba* sp.	Pigeon	240-370 g	185(141-225)	5,7,19
55	*Corvus cornix*	Hooded crow	360 g	378(312-492)	19,31
56	*Cygnus olor*	Mute swan	....	257	9
57	*Gallus domesticus*	Chicken	1,980 g	312(178-458)	19,31
58	*Gyps fulvus*	Griffon vulture	8,310 g	199	19,31
59	*Larus canus*	Mew gull	388 g	401(360-483)	19,31
60	*Meleagris gallopavo*	Turkey	8,750 g	93	19,31
61	*Passer domesticus*	House sparrow	28 g	350[2]; 902[3]	24
62			20 g	(640-910)	8,25
63	*Serinus canarius*	Canary	16 g	514[2]; 1,000[3]	24
64	*Struthio camelus*	African ostrich	80 kg	65(60-70)	8
65	*Sturnus vulgaris*	Starling	....	388(375-400)	37
66	*Troglodytes aedon*	House wren	11 g	450[2]; 950[3]	24
67	*Turdus migratorius*	American robin	....	570(520-620)	37
68	*Zenaidura macroura*	Mourning dove	130 g	135[2]; 570[3]	24
		Reptilia and Amphibia			
69	*Alligator mississipiensis*	American alligator	....	38	35
70	*Anguis fragilis*	Slowworm	....	64	19
71	*Bufo* sp.	Toad	....	(40-50)	19
72	*Caretta* sp.	Loggerhead turtle	....	11	19
73	*Emys orbicularis*	European pond turtle	....	(9-60)	19

/1/ Anesthetized. /2/ Basal rate. /3/ Maximum rate on nest.

continued

77. HEART RATES

Part II. VERTEBRATES OTHER THAN MAN

	Species	Common Name	Specification	Heart Rate beats/min	Reference
	(A)	(B)	(C)	(D)	(E)
	Reptilia and Amphibia				
74	*Natrix natrix*	European water snake	169 g	(23-41)	6,19
75	*Pseudemys terrapen rugosa*	Cuban freshwater turtle	....	(21-44)	19
76	*Rana pipiens*	Leopard frog	....	(37.5-60.0)	19
77	*Salamandra* sp.	Salamander	....	(30-40)	28
	Pisces and Chondrichthyes				
78	*Anguilla* sp.	Freshwater eel	....	(39-68)	19
79	*Carassius auratus*	Goldfish	....	(36-40)	19
80	*Cyprinus carpio*	Common carp	....	75(72-78)	37
81	*Esox lucius*	Northern pike	....	(38-54)	3
82	*Gadus morhua*	Atlantic cod	....	(48-60)	3
83	*Ictalurus* sp.	Bullhead	....	22(5-50)	14
84	*Melanogrammus* sp.	Haddock	....	(30-40)	32
85	*Micropterus salmoides*	Largemouth black bass	....	20(5-50)	14
86	*Perca fluviatilis*	European perch	....	(52-66)	3
87	*Pleuronectes platessa*	European plaice	....	(54-76)	3
88	*Raja* sp.	Skate	....	(16-50)	19
89	*Salmo trutta*	Brown trout	....	(30-46)	3
90	*Squalus acanthias*	Atlantic spiny dogfish	....	(40-50)	3

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continued

77. HEART RATES

Part III. INVERTEBRATES

Values are for adult animals, unless otherwise specified.

	Class	Species	Common Name	Specification	Heart Rate beats/min	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
			Chordata			
1	Ascidiacea	*Ciona intestinalis*	Sea squirt	....	(17-32)	16
2		*Molgula manhattensis*	Sea squirt	21-22°C	(30-50)	20
			Arthropoda			
3	Merostomata	*Limulus polyphemus*	King crab	....	20(18-28)	5
4	Crustacea	*Astacus fluviatilis*	Crayfish	....	(30-60)	13,20,27
5		*Callinectes sapidus*	Blue crab	22-23°C	(25-84)	10
6		*Daphnia pulex*	Water flea	0.0008 g; 20°C	(381-418)	30
7				0.000025 g; 20°C	486	
8		*Homarus gammarus*	European lobster	450 g; 20°C	50	30
9	Insecta	*Anopheles quadrimaculatus*	Malaria mosquito	Larva, stage 1; 25-27°C	131.7	15
10				Larva, stage 2; 25-27°C	134.3	
11				Larva, stage 3; 25-27°C	118.6	
12				Larva, stage 4; 25-27°C	106.6	
13				Pupa; 25-27°C	109.1	
14				Adult, ♀; 25-27°C	151.2	
15		*Anthophora retusa*	Digger bee	....	142	17
16		*Bombyx mori*	Silkworm	Resting	(40-50)	24
17				Active	(110-140)	24
18				Larva, calm	(44-66)	22
19				Larva, excited	94	22
20		*Calliphora* sp.	Blowfly	Larva; 18°C	60[1]	21
21		*Drosophila funebris*	Fruit fly	28-29°C	235	26
22		*Dytiscus marginalis*	Diving beetle	Intact	(30-70)	11
23		*Ephestia kuehniella*	Mediterranean flour moth	Pupa	(6-11)	36
24		*Locusta migratoria*	Migratory locust	♂; 26°C	(25-100)[1]	34
25				♂; 29°C	(80-120)[1]	
26				♀; 29°C	(80-130)[1]	
27		*Melanoplus differentialis*	Differential grasshopper	Nymph to adult; 21-26°C	(40-70)	14
28		*Pediculus* sp.	Louse	....	(30-48)	23
29		*Periplaneta americana*	American cockroach	18°C	72.9(22-150)[1]	2
30				Nymph to adult; 29°C	49(18-70)[1]	35
31				Nymph to adult; 26-27°C	(90-100)[1]	25
32				Nymph to adult; 20-26°C	117.3(99-147)	1
33				Nymph, ♂	94	8
34				Nymph, ♀	100	8
35		*Pieris brassicae*	European cabbageworm	Larva	29	32
36		*Prodenia eridania*	Southern armyworm	Larva; 29°C	58(40-90)[1]	35
37		*Tenebrio molitor*	Yellow mealworm	Pupa	10	28
38				Larva	(15-17)	28
39				Adult	(19-57)	3
			Annelida			
40	Hirudinea	*Hirudo* sp.	Leech	....	6	12
41	Oligochaeta	*Lumbricus terrestris*	Earthworm	....	17(15-20)	7
42	Polychaeta	*Arenicola* sp.	Lugworm	....	7(6-8)	6
43		*Nereis virens*	Clam worm	35°C	50	29
44				7°C	4.6	
			Mollusca			
45	Cephalopoda	*Loligo* sp.	Squid	....	(60-80)	5
46		*Sepia officinalis*	Cuttlefish	Perfused median ventricle, in situ	(18-30)	18,19
47	Bivalvia	*Mytilus edulis*	Mussel	0.104 g; 20°C	49.2	31
48		*Ostrea edulis*	Oyster	....	(25-30)	33
49		*Pecten jacobaeus*	Scallop	....	(22-50)	7,9
50	Gastropoda	*Aplysia limacina*	Sea hare	870 g; 20°C	28	31
51				347 g; 20°C	32.3	

/1/ Heart exposed by dissection and examined under physiological saline.

continued

77. HEART RATES

Part III. INVERTEBRATES

	Class	Species	Common Name	Specification	Heart Rate beats/min	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
			Mollusca			
52	Gastropoda	***Helix pomatia***	Land snail	36.7 g; 20°C	37.1	31
53				0.63 g; 20°C	47.6	
54				0.123 g; 20°C	60.3	
55		***Lymnaea stagnalis***	Freshwater snail	3.16 g; 20°C	21	31
56				0.00078 g; 20°C	55.4	
57	Polyplacophora	***Ischnochiton*** sp.	Chiton	....	(15-25)	4,5

Contributors: (a) Jones, Jack Colvard, (b) Kruta, Vladislav, (c) Robb, Jane Sands, (d) Nardone, Roland M., (e) Johnson, Richard P.

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78. ARTERIAL BLOOD PRESSURE

Part I. MAN

Number of subjects: line 1, 24 infants; lines 7-18, 3,580 children; lines 19-42, 7,222 males and 7,984 females; lines 43-56, 2,998 males and 2,759 females. Values in parentheses are ranges, estimate "b" (cf. Introduction).

	Age	Sex	Blood Pressure, mm Hg		Reference
			Systolic	Diastolic	
	(A)	(B)	(C)	(D)	(E)
1	Newborn	♂♀	80(64-96)	46(30-62)	5
2	6 mo-1 yr	♂♀	89(60-118)	60(50-70)[1]	1
3	1 yr	♂♀	96(66-126)	66(41-91)[1]	
4	2 yr	♂♀	99(74-124)	64(39-89)[1]	1
5	3 yr	♂♀	100(75-125)	67(44-90)[1]	
6	4 yr	♂♀	99(79-119)	65(45-85)[1]	

/1/ Point of muffling taken as the diastolic pressure.

continued

78. ARTERIAL BLOOD PRESSURE

Part I. MAN

	Age	Sex	Blood Pressure, mm Hg Systolic	Blood Pressure, mm Hg Diastolic	Reference
	(A)	(B)	(C)	(D)	(E)
7	5 yr	♂♀	94(80-108)	55(46-64)	2
8	6 yr	♂♀	100(85-115)	56(48-64)	
9	7 yr	♂♀	102(87-117)	56(48-64)	
10	8 yr	♂♀	105(89-121)	57(48-66)	
11	9 yr	♂♀	107(91-123)	57(48-66)	
12	10 yr	♂♀	109(93-125)	58(49-67)	
13	11 yr	♂♀	111(94-128)	59(49-69)	
14	12 yr	♂♀	113(95-131)	59(49-69)	
15	13 yr	♂♀	115(96-134)	60(50-70)	
16	14 yr	♂♀	118(99-137)	61(51-71)	
17	15 yr	♂♀	121(102-140)	61(51-71)	
18	16 yr	♂♀	121(102-140)	61(51-71)	
19	17 yr	♂	121(96-146)	74(56-93)	3
20		♀	116(93-139)	72(54-90)	
21	18 yr	♂	120(96-143)	74(55-94)	
22		♀	116(94-139)	72(55-89)	
23	19 yr	♂	122(92-151)	75(54-95)	
24		♀	115(92-138)	71(54-89)	
25	20-24 yr	♂	123(96-150)	76(57-96)	
26		♀	116(93-139)	72(53-91)	
27	25-29 yr	♂	125(100-150)	78(60-95)	
28		♀	117(94-139)	74(56-92)	
29	30-34 yr	♂	126(99-153)	79(60-98)	
30		♀	120(92-147)	75(54-96)	
31	35-39 yr	♂	127(99-155)	80(60-101)	
32	35-39 yr	♀	124(97-151)	78(58-98)	3
33	40-44 yr	♂	129(100-159)	81(63-100)	
34		♀	127(94-161)	80(59-100)	
35	45-49 yr	♂	130(97-163)	82(61-103)	
36		♀	131(92-169)	82(59-104)	
37	50-54 yr	♂	135(97-172)	83(61-106)	
38		♀	137(96-179)	84(59-108)	
39	55-59 yr	♂	138(101-175)	84(62-106)	
40		♀	139(97-180)	84(61-106)	
41	60-64 yr	♂	142(100-183)	85(60-109)	
42		♀	144(100-188)	85(60-110)	
43	65-69 yr	♂	143(92-194)	83(64-102)	4
44		♀	154(97-211)	85(58-112)	
45	70-74 yr	♂	145(93-197)	82(52-112)	
46		♀	159(108-210)	85(55-115)	
47	75-79 yr	♂	146(104-188)	81(56-106)	
48		♀	158(106-210)	84(58-110)	
49	80-84 yr	♂	145(95-195)	82(63-101)	
50		♀	157(102-212)	83(57-109)	
51	85-89 yr	♂	145(98-192)	79(50-108)	
52		♀	154(99-209)	82(48-116)	
53	90-94 yr	♂	145(99-191)	78(54-102)	
54		♀	150(104-196)	79(55-103)	
55	95-106 yr	♂	146(92-200)	78(53-103)	
56		♀	149(103-195)	81(57-106)	

Contributors: (a) Master, Arthur M., (b) Van Liere, Edward J., and Lindsay, Hugh A., (c) Hartroft, W. Stanley

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Part II. ANIMALS OTHER THAN MAN

Values are for adult animals, unless otherwise specified. Values in parentheses are ranges, estimate "c" (cf. Introduction).

	Species	Common Name	Subjects	Anesthetic	Blood Pressure, mm Hg Systolic (Mean)	Blood Pressure, mm Hg Diastolic (Mean)	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Mammalia						
1	*Bos taurus*	Cattle	.....	None	134(124-166)	88(80-120)	16
2		Young	4	....	157(133-177)		15
3	*Canis familiaris*	Dog	13	None	112(95-136)	56(43-66)	27
4			22	Pentobarbital	149(108-189)	100(75-122)	21
5			67♂	Sodium barbital	134(85-190)		26
6			80♀	Sodium barbital	125(60-170)		26
7	*Capra hircus*	Goat	.....	None	120(112-126)	84(76-90)	16
8	*Cavia porcellus*	Guinea pig	8	Ether, pentobarbital, and/or procaine	77(28-140)	47(16-90)	17
9	*Didelphis* sp.	Opossum	.....	....	(120-135)		15
10	*Equus caballus*	Horse	173♂	None	98(90-104)	64(45-86)	6

continued

78. ARTERIAL BLOOD PRESSURE

Part II. ANIMALS OTHER THAN MAN

	Species	Common Name	Subjects	Anesthetic	Blood Pressure, mm Hg: Systolic	Blood Pressure, mm Hg: Diastolic	Reference
					Mean		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Mammalia						
11	*Equus caballus*	Horse	43♀	None	90(86-98)	59(43-84)	6
12		Young	5♂, 3♀	None	80	50	6
13	*Felis catus*	Cat	5	Barbital or ether	120	75	28
14			191♂	Dial-urethan	129(67-216)		22
15			208♀	Dial-urethan	121(62-200)		22
16		Newborn	.....	....	(25-30)	....	1
17	*Macaca mulatta*	Rhesus monkey	14	None	159(137-188)	127(112-152)	24
18	*Mesocricetus auratus*	Golden hamster	.....	Pentobarbital	(120-170)		5
19	*Mus musculus*	House mouse	9	Urethan or ether	113(95-125)	81(67-90)	29
20		Young	19	None	111(95-138)	....	30
21	*Ornithorhynchus* sp.	Platypus	2♂, 1♀	....	14	....	9
22	*Oryctolagus cuniculus*	European rabbit	32	None	110(95-130)	80(60-90)	19
23		Young	.....	....	21	....	1
24		Newborn	1	....	35	1	11
25	*Ovis aries*	Sheep	13	Local	114(90-140)		7
26		Newborn	.....	....	73		1
27	*Phoca vitulina*	Harbor seal, young	1	....	ca. 135		14
28	*Rattus norvegicus*	Norway rat	124	Pentobarbital	129(88-184)	91(58-145)	23
29			100	None	98(82-120)	....	10
30		Young	18♂	Ether and/or amytal	124		8
31			23♀	Ether and/or amytal	116		8
32	*Sus scrofa*	Swine	.....	None	169(144-185)	108(98-120)	16
	Aves						
33	*Anas platyrhynchos*	Mallard duck	.....	....	162		15
34	*Anser* sp.	Goose	.....	....	(129-176)		15
35	*Columba livia*	Street pigeon	4	None	135(120-140)	105(100-115)	29
36	*Corvus cornix*	Hooded crow	.....	....	147		15
37	*Gallus domesticus*	Chicken	5	Barbital	130	85	28
38			13♂	....	135	120	7
39			♀	....	(88-171)		15
40	*Larus canus*	Mew gull	.....	....	179		15
41	*Meleagris gallopavo*	Turkey	.....	....	193		15
42	*Passer domesticus*	House sparrow	1	None	180	140	29
43		Fledgling	2	None	123(115-130)	....	29
44		Pinfeatherer	3	None	108(80-135)	....	29
45	*Serinus canarius*	Canary	4	None	220(200-250)	154(150-160)	29
46	*Sturnus vulgaris*	Starling	2	None	180(150-210)	130(100-160)	29
47	*Turdus migratorius*	American robin	2	None	118(110-125)	80	29
	Reptilia and Amphibia						
48	*Bufo terrestris*	Southern toad	.....	....	48		15
49	*Natrix natrix*	European water snake	.....	....	89		15
50	*Pseudemys scripta elegans*	Red-eared turtle	5	....	31[1]; 27[2]	25[1]; 21[2]	20
51	*Rana catesbeiana*	American bullfrog	6	None	43(36-56)	31(24-44)	29
52			6	None	32(28-36)	21(20-24)	2
53	*R. pipiens*	Leopard frog	6	None	31(21-33)	21(16-26)	2
	Pisces and Chondrichthyes						
54	*Anguilla* sp.	Freshwater eel	.....	....	(65-70)		15
55	*Cyprinus carpio*	Carp	3	None	43(40-45)	....	29
56	*Esox lucius*	Northern pike	.....	....	(35-84)		15
57	*Ictalurus punctatus*	Channel catfish	.....	....	40	30	12
58			.....	....	30	23	13
59	*Micropterus salmoides*	Largemouth black bass	.....	....	50	40	12
60	*Raja punctulata*	Skate	.....	....	16	7	18
61	*Salmo* sp.	Salmon	.....	....	75(47-120)		15
62	*Squalus acanthias*	Atlantic spiny dogfish	.....	....	32	28	3

/1/ At 22°C. /2/ At 16°C.

continued

78. ARTERIAL BLOOD PRESSURE

Part II. ANIMALS OTHER THAN MAN

	Species	Common Name	Sub-jects	Anesthetic	Blood Pressure, mm Hg: Systolic	Blood Pressure, mm Hg: Diastolic	Ref-er-ence
					Mean		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Crustacea						
63	*Astacus marinus*	Crayfish	.....	....	8.5		15
64	*Cancer irroratus*	Edible crab	6	....	8	....	4
65	*Homarus americanus*	American lobster	14[3]; 1[4]	....	13[3]; 27[4]	1[3]; 13[4]	4
	Gastropoda						
66	*Aplysia* sp.	Sea hare	.....	....	(20-40)	....	25

/3/ At rest. /4/ During activity.

Contributors: (a) Van Liere, Edward J., and Lindsay, Hugh A., (b) Conklin, Ruth E., (c) Freed, S. Charles, (d) Freis, Edward D., (e) Heisler, Charles R., (f) Link, Roger P., (g) Rodbard, Simon, (h) Woodbury, Robert A.

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79. VASCULAR AND CAPILLARY PRESSURES

Part I. VASCULAR PRESSURES: MAN

	Chamber or Vessel	Blood Pressure, mm Hg: Systolic	Blood Pressure, mm Hg: Diastolic	Blood Pressure, mm Hg: Mean	Method	Refer-ence
	(A)	(B)	(C)	(D)	(E)	(F)
1	Medium veins	....	......	4-7	Direct measurement	3
2	Venae cavae	....	......	-5 to +5	Right heart catheterization	4
3	Right atrium	2-7	0-5	1-5	Right heart catheterization	2
4	Right ventricle	19-31	2-6	....	Right heart catheterization	2
5	Pulmonary artery	16-29	5-13	10-18	Right heart catheterization	2
6	Pulmonary capillary	....	......	5-13	Right heart catheterization	1
7	Left atrium	6-21	1-12	2-12	Transseptal left heart catheterization	1
8	Left ventricle	90-130	5-12	....	Transseptal left heart catheterization	1
9	Aorta	90-130	60-90	70-115	....	4

continued

79. VASCULAR AND CAPILLARY PRESSURES

Part I. VASCULAR PRESSURES: MAN

Contributors: Terry, Luther L., and Braunwald, Eugene

References: [1] Braunwald, E., et al. 1961. Circulation 24:267. [2] Fowler, N. O., et al. 1953. Am. Heart J. 46:264. [3] Snabel, T. G., Jr., et al. 1954. Penna. Med. J. 57:363. [4] Terry, L. L. Unpublished. Natl. Institutes of Health, Bethesda, Md., 1955.

Part II. RELATIONSHIP OF PERIPHERAL ARTERIAL TO CENTRAL ARTERIAL PRESSURE: MAN

Values are expressed as percent of aorta pressure or of subclavian pressure near the aorta.

	Condition	Artery	Blood Pressure Systolic	Diastolic	Mean
	(A)	(B)	(C)	(D)	(E)
1	Supine, at rest	Brachial	109	96	98
2		Radial	112	93	94
3		Femoral	110	94	96
4	Supine, during exercise	Brachial	111	97	97
5		Radial	113	93	93
6		Femoral	101	95	97
7	70° head-up tilt	Brachial	111	98	99
8		Radial	115	95	98
9		Femoral	123	98	100

Contributor: Terry, Luther L.

Reference: Kroeker, E. J., and E. H. Wood. 1955. Circulation Res. 3:623.

Part III. VENOUS BLOOD PRESSURE: MAN

Reference level was the phlebostatic axis. Subjects were supine, breathing quietly. Forced respiration (e.g., Valsalva's maneuver) profoundly influences venous pressure. Values in parentheses are ranges, estimate "c" (cf. Introduction).

	Vein	Blood Pressure mm H_2O
	(A)	(B)
	Median basilic vein at elbow	
1	3-5 yr	46(30-63)
2	5-10 yr	58(33-74)
3	Adult ♀	94(60-128)
4	Adult ♂	100(50-140)
5	Femoral	111(98-128)
6	Abdominal	115(70-160)
7	Dorsal metacarpal	130(70-170)
8	Great saphenous at ankle	150(110-190)
9	Dorsal pedal	175(124-210)

Contributor: Terry, Luther L.

Reference: Burch, G. E. 1950. A primer of venous pressure. Lea and Febiger, Philadelphia.

Part IV. CAPILLARY BLOOD PRESSURE: VERTEBRATES

All measurements made directly by microcannulation [1]. Capillary (column D): A = arterial; V = venous. Values in parentheses are ranges, estimate "c" (cf. Introduction).

	Tissue	Species (Common Name)	Condition	Capillary	Pressure cm H_2O	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
1	Eponychium (finger)	*Homo sapiens* (man)	Normal	A	43.5(28.6-65.0)/1/	5,7
2				V	16.5(8.0-24.5)/1/	
3			Hypertension	A	48.5(10.1-95.1)	2
4				V	30.8(12.8-58.0)	
5			Hyperemia	A	86.0(71.0-93.0)	7
6				V	(54.5-66.5)	
7	Mesentery	*Cavia porcellus* (guinea pig)	Decerebrate; anesthetized with veronal ether	A	38.5(31.0-49.0)	4,7
8				V	17.0(13.0-19.5)	
9		*Rattus* sp. (rat)	Decerebrate	A	30.0(22.0-34.0)	4,7
10				V	17.0(15.0-20.0)	
11		*Rana* sp. (frog)	Pithed	A	14.4(5.0-22.0)	3,7
12				V	10.1(6.7-18.0)	

/1/ Varies directly with arteriolar vasodilation produced by emotion, heat, or trauma. Varies inversely with arteriolar vasoconstriction produced by emotion or cold. Varies minimally in a single capillary with time, and also from capillary to capillary. Varies directly with venous pressure as affected by hydrostatic pressure or venous obstruction.

continued

79. VASCULAR AND CAPILLARY PRESSURES: VERTEBRATES

Part IV. CAPILLARY BLOOD PRESSURE: VERTEBRATES

	Tissue	Species (Common Name)	Condition	Capillary	Pressure cm H_2O	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
13	Muscle	*Rana* sp. (frog)	Normal; anesthetized with urethan	A	14.9(11.0-18.0)	6,7
14				V	9.5(7.0-12.7)	
15			Hyperemia	A	20.1(17.0-26.0)	7
16				V	16.0(12.0-17.5)	
17	Web	*Rana* sp. (frog)	Normal; anesthetized with urethan	A	13.9(10.0-19.0)	6,7
18				V	9.6(8.5-13.0)	
19			Normal; curarized	A	14.5(10.0-20.5)	7
20				V	10.0(8.5-15.5)	
21			Hyperemia	A	19.5(14.0-26.5)	7
22				V	16.5(15.0-17.5)	

Contributors: (a) Griffith, John Quintin, Jr., (b) Mendlowitz, Milton

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VIII. BLOOD

80. BLOOD GROUP SYSTEMS: MAN

The A-B-O, the M-N, and the Rh-Hr are the three most important blood group systems in man and are the ones most used in the study of human linkage, in tests for zygosity of twins, and in medicolegal problems of disputed parentage. Other blood group systems have been reported after an antibody giving reactions unrelated to previously described blood groups has been encountered in the serum of certain individuals (mothers of erythroblastotic babies [Kell, Kidd], patients who had received blood transfusions [Duffy, Lutheran]). The blood group systems in man depend on multiple allelic genes for their hereditary transmission. None of the blood-grouped genes is known to be sex-linked, and the genes of each blood group system appear to be located on different pairs of chromosomes, as is shown by their independent heredity. For information on other blood group systems, consult reference 1, Part I.

Definitions: **agglutinin** = an antibody aggregating a particular antigen; **agglutinogen** = any substance that acts as an antigen and stimulates the production of agglutinin; **antiserum** = a serum containing an antibody or antibodies; **antibody** = a modified serum globulin, synthesized by an animal in response to antigenic stimulus, that reacts specifically in vivo and in vitro with the homologous antigen; **antigen** = a high-molecular-weight substance, or complex, foreign to the blood stream, that, upon gaining access to the tissues of the animal, stimulates the formation of a specific antibody and reacts specifically in vivo or in vitro with the homologous antibody; **blood factors** = the specific serological properties by which an agglutinogen is recognized, e.g., if blood cells are clumped by an antiserum assigned the symbol anti-**X**, they are said to have blood factor **X**; **gene** = the biologic unit of heredity, self-reproducing and located in a definite position (locus) on a particular chromosome; **allelic genes** = genes situated at corresponding loci in a pair of chromosomes; **genotype** = the fundamental hereditary constitution (or assortment of genes) of an individual; **phenotype** = the outward, visible expression of the hereditary constitution of an individual.

Part I. PHENOTYPES AND GENOTYPES OF THE A-B-O SYSTEM

The A-B-O blood groups are determined by two agglutinogens on the red blood cells (agglutinogen A which occurs in two principal forms, A_1 and A_2, and agglutinogen B) and two corresponding, naturally occurring isoagglutinins in the serum (anti-**A** [alpha] and anti-**B** [beta]). The latter are regularly present in the serum when the corresponding agglutinogen is absent from the red cells, except during the neonatal period when the antibody-producing mechanism is immature. Tests include examination of the serum for isoagglutinin content, as well as examination of the reaction of the red cells to anti-**A** and anti-**B** serums. Anti-A was obtained from type-B subjects, and anti-**B** from type-A subjects. Frequencies (columns B and I) are for populations of European origin. *Xx* genes (column J) segregate independently of and modify *ABO* genes.

	Phenotype							Genotype		
	Designation	Frequency %	Reaction with Anti- A	Reaction with Anti- A_1	Reaction with Anti- B	Reaction with Anti- H	Plasma Agglutinin	ABO Genes	Frequency %	Xx Genes
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
1	O	45.0	-	-	-	+	Anti-**A**, anti-**B**	*OO*	45.0	*XX* or *Xx*
2	A_1	31.0	+	+	-	-	Anti-**B**, occasionally anti-**H**	A_1A_1	3.5	
3								A_1A_2	2.6	
4								A_1O	25.0	
5	A_2	9.6	+	-	-	+	Anti-**B**, occasionally anti-A_1	A_2A_2	0.5	
6								A_2O	9.2	
7	B	10.0	-	-	+		Anti-**A**	*BB*	0.7	
8								*BO*	9.3	
9	A_1B	2.9	+	+	+	-	Occasionally anti-**H**	A_1B	2.9	
10	A_2B	1.1	+	-	+		Occasionally anti-A_1	A_2B	1.1	
11	"Bombay type"	Rare	-	-	-	-	Anti-**A**, anti-**B** anti-**H**	*A,B,O*/1/	Rare	*xx*

/1/ Probably any combination is possible.

Contributor: Allen, Fred H., Jr.

References: [1] Altman, P. L., and D. S. Dittmer, ed. 1961. Blood and other body fluids. Federation of American Societies for Experimental Biology, Washington, D. C. [2] Race, R. R., and R. Sanger. 1958. Blood groups

continued

Part I. PHENOTYPES AND GENOTYPES OF THE A-B-O SYSTEM

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Part II. PARTIAL LIST OF ALLELIC GENES OF THE M-N SYSTEM

So far as is known, the M-N phenotype of a person is exactly what would be expected from the genotype, no suppressing effect of any one *M-N* gene on any other having been demonstrated. In blood typing, anti-**M** is obtained from humans or immunized rabbits, anti-**N** from immunized rabbits or from seeds of *Vicia graminea*, anti-**Hu** and anti-**He** are obtained only from immunized rabbits, and other antiserums only from sensitized humans. Blood factor frequencies are for Europeans and are given in parentheses.

	Gene	Gene Frequency %	Reaction with Anti- M (79%)	M^g (Rare)	N (71%)	S (55%)	s (89%)	U (99+%)	Hu (Rare[1])	He (Rare[1])	Mi^a (Rare[1])	Vw (Rare[1])	Vr (Rare[1])
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)
1	*MS*	25	+	-	+[2]	+	-	+	-	±	±	-	-
2	*Ms*	28	+	-	+[2]	-	+	+	-	±	-	-	±
3	MS^u	Rare	+	-	-	-	-	-	-	-	-	-	
4	*NS*	8	-	-	+	+	-	+	-	±	-	-	-
5	*Ns*	39	-	-	+	-	+	+	±	±	±	±	-
6	NS^u	Rare	-	-	+	-	-	-	-	-	-	-	
7	M^g	Rare	-	+		-			-	-	-	-	-
8	*MU*	Rare	+	-	-	-	-	+					
9	*NU*	Rare	-	-	+	-	-	+					

/1/ Factors **Hu**, **He**, $\mathbf{Mi^a}$, **Vw**, and **Vr** undoubtedly occur in other combinations than are shown here, but there is, as yet, insufficient information about these factors to prepare a complete table of the *M-N* genes. Other antigenic factors in the MN system are $\mathbf{M_1}$, $\mathbf{M^c}$, $\mathbf{M^e}$, **Mu**, $\mathbf{Mt^a}$, $\mathbf{St^a}$, $\mathbf{Ri^a}$, $\mathbf{Cl^a}$, and $\mathbf{Ny^a}$. All except $\mathbf{M^e}$ are rare. $\mathbf{M^e}$ is produced by *M* genes and by genes that produce **He**. /2/ These genes produce a small amount of **N** factor or something which cross-reacts with anti-**N**.

Contributor: Allen, Fred H., Jr.

References: [1] Allen, F. H., Jr., P. A. Corcoran, and F. R. Ellis. 1960. Vox Sanguinis 5:224. [2] Allen, F. H., Jr., et al. 1958. Ibid. 3:81. [3] Cleghorn, T. E. 1961. M.D. Thesis. Univ. Sheffield, England. [4] Cleghorn, T. E. 1962. Nature 195:297. [5] Dunsford, I., E. W. Ikin, and A. E. Mourant. 1953. Ibid. 172:688. [6] Graydon, J. J. 1946. Med. J. Australia 2:9. [7] Ikin, E. W., and A. E. Mourant. 1951. Brit. Med. J. 1:456. [8] Jack, J. A., et al. 1960. Nature 186:642. [9] Landsteiner, K., and P. Levine. 1927. Proc. Soc. Exptl. Biol. Med. 24:600. [10] Landsteiner, K., W. R. Strutton, and M. W. Chase. 1934. J. Immunol. 27:469. [11] Levine, P., et al. 1951. Proc. Soc. Exptl. Biol. Med. 77:402. [12] Levine, P., et al. 1951. Ibid. 78:218. [13] Sanger, R., and R. R. Race. 1947. Nature 160:505. [14] Swanson, J., and G. A. Matson. 1962. Vox Sanguinis 7:585. [15] Van der Hart, M., et al. 1958. Ibid. 3:261. [16] Walsh, R. J., and C. Montgomery. 1947. Nature 160:504. [17] Wiener, A. S., and R. E. Rosenfield. 1961. J. Immunol. 87:376. [18] Wiener, A. S., L. J. Unger, and E. B. Gordon. 1953. J. Am. Med. Assoc. 153:1444.

continued

Part III. PHENOTYPES AND GENOTYPES OF THE Rh-Hr SYSTEM

The Rh-Hr system is the most complicated of the human blood systems. At the present time, four principal Rh blood factors (**Rh$_o$**, **rh'**, **rh''**, and **rh^W**) and three principal Hr factors (**hr'**, **hr''**, and **hr**) are recognized. However, antiserums for only five of these seven factors are readily available for routine clinical and medicolegal work (anti-**Rh$_o$**, anti-**rh'**, anti-**rh''**, anti-**hr'** and anti-**hr''**). The **Rh$_o$** factor is the most common source of clinical symptoms, as it is the most antigenic of the Rh-Hr factors. It appears to represent a special structure within the Rh-Hr agglutinogen, since red cells can be coated with the **Rh$_o$**-blocking antibody without interfering with the reactions of the red cells with other antibodies such as anti-**rh'**, anti-**rh''**, anti-**hr'**. Frequencies are for white residents of New York City. Frequencies (columns E and J) are based on estimated gene frequencies: r = 38%; r' = 0.6%; r'' = 0.5%; r^y = 0.01%; r'^w = 0.005%; R^o = 2.7%; R^1 = 41%; R^2 = 15%; R^z = 0.2%; R^{1w} = 2%.

	2 Rh Phenotypes			12 Rh Phenotypes					28 Rh-Hr Phenotypes					
	Designation	Frequency %	Reaction with Anti-Rh$_o$ (or Antirhesus)	Designation	Frequency %	Reaction with Anti- rh'	rh''	rh^W	Designation	Frequency %	Reaction with Anti- hr'	hr''	hr	55 Genotypes
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)
1	Rh negative	15	-	rh	14.4	-	-	-	rh	14.4	+	+	+	rr
2				rh'	0.46	+	-	-	rh'rh	0.46	+	+	+	$r'r$
3									rh'rh'	0.0036	-	+	-	$r'r'$
4				rh'w	0.004	+	-	+	rh'^{W}rh	[illegible]	+	+	+	$r'^w r$
5									rh'^{W}rh'	0.00006	-	+	-	$r'^w r'$ or $r'^w r'^w$
6				rh''	0.38	-	+	-	rh''rh	0.38	+	+	+	$r''r$
7									rh''rh''	0.0025	+	-	-	$r''r''$
8				rh^y	0.01	+	+	-	rh'rh''	0.006	+	+	-	$r'r''$
9									rh$_y$rh	0.008	+	+	+	$r^y r$
10									rh$_y$rh'	0.0001	-	+	-	$r^y r'$
11									rh$_y$rh''	0.0001	+	-	-	$r^y r''$
12									rh$_y$rh$_y$	0.000001	-	-	-	$r^y r^y$
13				rh^W_y	0.00005	+	+	+	rh'^{W}rh''	0.00005	+	+	-	$r'^w r''$
14									rh^W_yrh'	0.000001	-	+	-	$r'^w r^y$
15	Rh positive	85	+	Rh$_o$	2.1	-	-	-	Rh$_o$	2.1	+	+	+	R^oR^o or R^or
16				Rh$_1$	50.7	+	-	-	Rh$_1$rh	33.4	+	+	+	R^1r, R^1R^o, or R^or'
17									Rh$_1$Rh$_1$	17.3	-	+	-	R^1R^1 or R^1r'
18				Rh$^W_1$	3.3	+	-	+	Rh$^W_1$rh	1.6	+	+	+	$R^{1w}r$, $R^{1w}R^o$, or $R^or'^w$
19									Rh$^W_1$Rh$_1$	1.7	-	+	-	$R^{1w}R^1$, $R^1r'^w$, $R^{1w}r'$, $R^{1w}R^{1w}$, or $R^{1w}r'^w$
20				Rh$_2$	14.6	-	+	-	Rh$_2$rh	12.2	+	+	+	R^2r, R^2R^o, or R^or''
21									Rh$_2$Rh$_2$	2.4	+	-	-	R^2R^2 or R^2r''
22				Rh$_z$	13.4	+	+	-	Rh$_1$Rh$_2$	12.9	+	+	-	R^1R^2, R^1r'', or R^2r'
23									Rh$_z$rh	0.2	+	+	+	R^zr, R^zR^o, or R^or^y
24									Rh$_z$Rh$_1$	0.2	-	+	-	R^zR^1, R^zr', or R^1r^y
25									Rh$_z$Rh$_2$	0.07	+	-	-	R^zR^2, R^zr'', or R^2r^y
26									Rh$_z$Rh$_z$	0.0004	-	-	-	R^zR^z or R^zr^y
27				Rh^W_z	0.6	+	+	+	Rh$^W_1$Rh$_2$	0.6	+	+	-	$R^{1w}R^2$, $R^{1w}r''$, or $R^2r'^w$
28									Rh^W_zRh$_1$	0.008	-	+	-	$R^{1w}R^z$, $R^{1w}r^y$, or $R^zr'^w$

Contributor: Wiener, Alexander S.

Reference: Wiener, A. S., and I. B. Wexler. 1963. An Rh-Hr syllabus; the types and their application. Ed. 2. Grune and Stratton, New York.

continued

80. BLOOD GROUP SYSTEMS: MAN

Part IV. PARTIAL LIST OF ALLELIC GENES OF THE Rh-Hr SYSTEM

	Gene	Agglutinogen	Reaction with Anti-																		
			Rh_o	rh'	rh^{w1}	rh''	rh^{w2}	hr'	hr''	hr	Rh^A	Rh^B	Rh^C	Rh^D	rh^x	rh_i	rh^G	Hr	hr^S	hr^V	hr^N
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)	(P)	(Q)	(R)	(S)	(T)	(U)
1	r	rh	-	-	-	-	-	+	+	+	-	-	-	-	-	-	-	+	+	-	-
2	r'	rh'	-	+	-	-	-	-	+	-	-	-	-	-	-	+	+	+	+	-	-
3	$r'w$	rh'^{w}	-	+	+	-	-	-	+	-	-	-	-	-	-	+	+	+	+	-	-
4	r''	rh''	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-
5	r^y	rh_y	-	+	-	+	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-
6	R^o	Rh_o	+	-	-	-	-	+	+	+	+	+	+	+	-	-	+	+	+	-	-
7	R^1	Rh_1	+	+	-	-	-	-	+	-	+	+	+	+	-	+	+	+	+	-	-
8	R^{1w}	Rh_1^w	+	+	+	-	-	-	+	-	+	+	+	+	-	+	+	+	+	-	-
9	R^2	Rh_2	+	-	-	+	-	+	-	-	+	+	+	+	-	-	+	+	-	-	-
10	R^z	Rh_z	+	+	-	+	-	-	-	-	+	+	+	+	-	-	+	+	-	-	-
11	$\mathfrak{R}^o$	$\mathfrak{R}h_o$	±	-	-	-	-	+	+	+	±	±	±	±	-	-	+	+	+	-	-
12	$\mathfrak{R}^1$	$\mathfrak{R}h_1$	±	+	-	-	-	-	+	-	±	±	±	±	-	+	+	+	+	-	-
13	$\mathfrak{R}^2$	$\mathfrak{R}h_2$	±	-	-	+	-	+	-	-	±	±	±	±	-	-	+	+	-	-	-
14	$\bar{\bar{R}}^o$	$\bar{\bar{R}}h_o$	++	-	-	-	-	-	-	-	+	+	+	+	-	-	+	-	-	-	-
15	$\bar{\bar{R}}^w$	$\bar{\bar{R}}h^w$	++	-	+	-	-	-	-	-	+	+	+	+	-	-	+	-	-	-	-
16	$\bar{R}^o$	$\bar{R}h_o$	+	-	-	-	-	+	-	+	+	+	+	+	-	-	+	-	-	-	-
17	$\hat{R}^o$	$\hat{R}h_o$	+	-	-	-	-	+	+	+	+	+	+	+	-	-	+	-	-	-	-
18	$\bar{\bar{r}}$	$\bar{\bar{r}}h$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	R^{1x}	Rh_1^x	+	+	-	-	-	-	+	-	+	+	+	+	+	+	+	+	+	-	-
20	R^{2w}	Rh_2^w	+	-	-	+	+	+	-	-	+	+	+	+	-	-	+	+	-	-	-
21	r^v	rh^V	-	-	-	-	-	+	+	+	-	-	-	-	-	-	-	+	+	+	+
22	R^{ov}	Rh_o^V	+	-	-	-	-	+	+	+	+	+	+	+	-	-	+	+	+	+	+
23	r'^N	rh'^N	-	+	-	-	-	+	+	+	-	-	-	-	-	-	+	+	+	-	+
24	R^{1ab}	Rh_1^{ab}	+	+	-	-	-	-	+	-	-	-	+	+	-	+	+	+	+	-	-
25	R^{2b}	Rh_2^b	+	-	-	+	-	+	-	-	+	-	+	+	-	-	+	+	-	-	-
26	$\mathfrak{R}^{2c}$	$\mathfrak{R}h_2^c$	±	-	-	+	-	+	-	-	+	+	-	+	-	-	+	+	-	-	-
27	R^{od}	Rh_o^d	+	-	-	-	-	+	+	+	+	+	+	-	-	-	+	+	+	-	-
28	r^G	rh^G	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	+	-	-	-

Contributor: Wiener, Alexander S.

Reference: Wiener, A. S., and I. B. Wexler. 1963. An Rh-Hr syllabus; the types and their applications. Ed. 2. Grune and Stratton, New York.

81. HEREDITY OF BLOOD GROUPS AND TYPES: MAN

Because of the possibility of coincidence, it is considered an inconclusive finding when the blood type of the child matches the blood type of the putative parent. Therefore, in cases of disputed parentage, blood tests can be used only to exclude the claim of maternity or paternity.

Part I. A-B-O EXCLUSION

	Parental Phenotype Combination		Blood Group of Child that Refutes	
	Putative Mother	Putative Father	Putative Maternity	Putative Paternity
	(A)	(B)	(C)	(D)
1	O	O	AB	A, B
2		A	AB	B
3		B	AB	A
4		AB	AB	O
5	A	O	None	B, AB
6		A	None	B, AB
7		B	None	None
8		AB	None	O
9	B	O	None	A, AB
10		A	None	None
11		B	None	A, AB
12		AB	None	O
13	AB	O	O	AB
14		A	O	None
15		B	O	None
16		AB	O	None

Contributor: Wiener, Alexander S.

Reference: Wiener, A. S., and I. B. Wexler. 1958. Heredity of the blood groups. Grune and Stratton, New York.

Part II. M-N EXCLUSION

	Parental Phenotype Combination		Blood Type of Child that Refutes	
	Putative Mother	Putative Father	Putative Maternity	Putative Paternity
	(A)	(B)	(C)	(D)
1	M	M	N	MN
2		N	N	M
3		MN	N	None
4	N	M	M	N
5		N	M	MN
6		MN	M	None
7	MN	M	None	N
8		N	None	M
9		MN	None	None

Contributor: Wiener, Alexander S.

Reference: See Part I.

Part III. Rh-Hr EXCLUSION

This table is applicable only to matings in which at least one of the parents is **Rh_o**-positive. Where both parents are **Rh_o**-negative, all **Rh_o**-positive children are necessarily excluded. Boldface figures represent phenotypes of children for whom putative *maternity* is excluded; all other figures shown represent phenotypes of children for whom putative *paternity* is excluded. Code numbers and corresponding phenotypes are given in the column headings, e.g., 1 is the code number for phenotypes rh and Rh_o.

	Phenotype of Putative Mother	Phenotype of Putative Father: 1 rh Rh_o	2 rh'rh Rh_1rh	3 rh'rh' Rh_1Rh_1	4 rh''rh Rh_2rh	5 rh''rh'' Rh_2Rh_2	6a rh'rh'' Rh_1Rh_2	6b rh_yrh Rh_zRh_o	7 rh_yrh' Rh_zRh_1	8 rh_yrh'' Rh_zRh_2	9 rh_yrh_y Rh_zRh_z
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
1	1 rh Rh_o	2,3,4,5, 6a,6b, 7,8,9	3,4,5,6a, 6b,7,8, 9	1,3,4,5, 6a,6b, 7,8,9	2,3,5,6a, 6b,7,8, 9	1,2,3,5, 6a,6b, 7,8,9	1,3,5,6a, 6b,7,8, 9	2,3,4,5, 6a,7,8, 9	1,3,4,5, 6a,7,8, 9	1,2,3,5, 6a,7,8, 9	1,2,3,4, 5,6a,7, 8,9
2	2 rh'rh Rh_1rh	3,4,5, 6a,6b, 7,8,9	4,5,6a, 6b,7,8, 9	1,4,5, 6a,6b, 7,8,9	3,5,6b,7, 8,9	1,2,3,5, 6b,7,8, 9	1,5,6b,7, 8,9	3,4,5,6a, 8,9	1,4,5,6a, 8,9	1,2,3,5, 8,9	1,2,3,4, 5,6a,8, 9
3	3 rh'rh' Rh_1Rh_1	1,3,4,5, 6a,6b, 7,8,9	1,4,5,6a, 6b,7,8, 9	1,2,4,5, 6a,6b, 7,8,9	1,3,4,5, 6b,7,8, 9	1,2,3,4, 5,6b,7, 8,9	1,2,4,5, 6b,7,8, 9	1,3,4,5, 6a,6b, 8,9	1,2,4,5, 6a,6b, 8,9	1,2,3,4, 5,6b,8, 9	1,2,3,4, 5,6a, 6b,8,9
4	4 rh''rh Rh_2rh	2,3,5, 6a,6b, 7,8,9	3,5,6b,7, 8,9	1,3,4,5, 6b,7, 8,9	2,3,6a, 6b,7,8, 9	1,2,3,6a, 6b,7,8, 9	1,3,6b,7, 8,9	2,3,5,6a, 7,9	1,3,4,5, 7,9	1,2,3,6a, 7,9	1,2,3,4, 5,6a,7, 9
5	5 rh''rh'' Rh_2Rh_2	1,2,3,5, 6a,6b, 7,8,9	1,2,3,5, 6b,7,8, 9	1,2,3,4, 5,6b, 7,8,9	1,2,3,6a, 6b,7,8, 9	1,2,3,4, 6a,6b, 7,8,9	1,2,3,4, 6b,7,8, 9	1,2,3,5, 6a,6b, 7,9	1,2,3,4, 5,6b,7, 9	1,2,3,4, 6a,6b, 7,9	1,2,3,4, 5,6a, 6b,7,9
6	6a rh'rh'' Rh_1Rh_2	1,3,5,6a, 6b,7,8, 9	1,5,6b,7, 8,9	1,2,4,5, 6b,7, 8,9	1,3,6b,7, 8,9	1,2,3,4, 6b,7,8, 9	1,2,4,6b, 7,8,9	1,3,5,6a, 6b,9	1,2,4,5, 6b,9	1,2,3,4, 6b,9	1,2,3,4, 5,6a, 6b,9
7	6b rh_yrh Rh_zRh_o	2,3,4,5, 6a,7,8, 9	3,4,5,6a, 8,9	1,3,4,5, 6a,6b, 8,9	2,3,5,6a, 7,9	1,2,3,5, 6a,6b, 7,9	1,3,5,6a, 6b,9	2,3,4,5, 6a,7,8	1,3,4,5, 6a,8	1,2,3,5, 6a,7	1,2,3,4, 5,6a, 7,8

continued

81. HEREDITY OF BLOOD GROUPS AND TYPES: MAN

Part III. Rh-Hr EXCLUSION

	Phenotype of Putative Mother		Phenotype of Putative Father									
			1	2	3	4	5	6a	6b	7	8	9
			rh Rh_o	rh'rh Rh_1rh	rh'rh' Rh_1Rh_1	rh"rh Rh_2rh	rh"rh" Rh_2Rh_2	rh'rh" Rh_1Rh_2	rh_yrh Rh_zRh_o	rh_yrh' Rh_zRh_1	$rh_yrh"$ Rh_zRh_2	rh_yrh_y Rh_zRh_z
	(A)		(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
8	7	rh_yrh' Rh_zRh_1	1,3,4,5, 6a,7,8, 9	1,4,5,6a, 8,9	1,2,4,5, 6a,6b, 8,9	1,3,4,5, 7,9	1,2,3,4, 5,6b,7, 9	1,2,4,5, 6b,9	1,3,4,5, 6a,8	1,2,4,5, 6a,6b, 8	1,2,3,4, 5,6b	1,2,3,4, 5,6a, 6b,8
9	8	$rh_yrh"$ Rh_zRh_2	1,2,3,5, 6a,7,8, 9	1,2,3,5, 8,9	1,2,3,4, 5,6b, 8,9	1,2,3,6a, 7,9	1,2,3,4, 6a,6b, 7,9	1,2,3,4, 6b,9	1,2,3,5, 6a,7	1,2,3,4, 5,6b	1,2,3,4, 6a,6b, 7	1,2,3,4, 5,6a, 6b,7
10	9	rh_yrh_y Rh_zRh_z	1,2,3,4, 5,6a,7, 8,9	1,2,3,4, 5,6a,8 9	1,2,3,4, 5,6a, 6b,8,9	1,2,3,4, 5,6a,7, 9	1,2,3,4, 5,6a, 6b,7,9	1,2,3,4, 5,6a, 6b,9	1,2,3,4, 5,6a,7, 8	1,2,3,4, 5,6a, 6b,8	1,2,3,4, 5,6a, 6b,7	1,2,3,4, 5,6a, 6b,7,8

Contributor: Wiener, Alexander S.

Reference: Wiener, A. S. 1963. J. Forensic Med. 10(1):6.

82. DISTRIBUTION OF BLOOD GROUPS AND TYPES IN VARIOUS POPULATIONS: MAN

Part I. A-B-O GROUPS

	Population	Location	No. of Subjects	Frequency, %			
				Group O	Group A	Group B	Group AB
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
1	Ainu	Shizunai	504	36.7	44.5	14.7	5.1
	American Indian						
2	Blackfoot	Montana	115	23.5	76.5	0	0
3	Navaho	Arizona	457	72.9	26.9	0.2	0.2
4	Pueblo	New Mexico	310	78.4	20.0	1.6	0
5	Ute	Utah	104	98.1	1.9	0	0
6	Armenian	Vicinity of Marash, Turkey	330	27.3	53.9	12.7	6.1
7	Australian aborigine	Australia	805	53.1	44.7	2.1	0
8	Australian white	Sydr	220	44.6	43.6	9.1	2.7
9	Basque	San Sebastian, Spain	91	57.2	41.7	1.1	0
	Bedouin						
10	Iraqi	Vicinity of Baghdad	338	40.8	26.6	25.8	6.8
11	Rwala	Syrian Desert	208	43.3	22.1	30.3	4.3
12	Belgian	Liège	3,500	46.7	41.9	8.3	3.1
13	Chinese	Peking	1,000	30.7	25.1	34.2	10.0
14	Danish	Copenhagen	14,304	40.6	44.0	10.9	4.5
15	Dutch	Amsterdam	23,643	44.4	43.2	8.9	3.5
16	Egyptian	Cairo	502	27.3	38.5	25.5	8.8
17	English	Southern England	106,477	45.2	43.2	8.5	3.1
18	Eskimo	Southwest Greenland	1,063	46.0	46.1	4.9	3.0
19	Estonian	Central, southern, and southeastern Estonia	1,844	32.3	36.6	22.4	8.7
20	Fijian	Fiji Islands	160	43.8	43.1	9.4	3.8
21	Filipino	Philippine Islands	382	45.0	22.0	27.0	6.0
22	Finnish	Finland	23,200	34.1	41.0	18.0	6.9
23	French	Paris	14,303	42.7	45.6	8.3	3.3
24	German	Berlin	39,174	36.5	42.5	14.5	6.5
25	Greek	Athens	21,635	43.5	38.6	13.1	4.8
26	Hindu	Calcutta	6,247	32.4	24.1	36.2	7.3
27	Hungarian	Budapest	624	36.1	41.8	15.9	6.2
28	Indonesian	Djakarta	7,129	39.2	26.8	27.3	6.7
29	Irish	Northern Ireland	10,784	52.0	34.7	10.4	2.9
30	Italian	Rome and vicinity	20,051	44.7	40.0	11.4	3.8
31	Japanese	Tokyo	33,834	31.2	38.4	21.8	8.6
32	Korean	South Korea (north of Seoul)	1,000	27.0	32.0	29.0	12.0
33	Norwegian	Oslo	8,292	37.8	50.0	8.2	4.0

continued

82. DISTRIBUTION OF BLOOD GROUPS AND TYPES IN VARIOUS POPULATIONS: MAN

Part I. A-B-O GROUPS

	Population	Location	No. of Subjects	Frequency, % Group O	Group A	Group B	Group AB
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
34	Pakistani, Punjabi	Vicinity of Quetta, West Pakistan	10,000	30.6	24.5	34.8	10.0
35	Papuan	Papua	753	53.7	26.8	16.3	3.2
36	Polish	Warsaw	2,886	33.1	38.9	20.1	7.9
37	Portuguese	Lisbon	7,502	41.8	47.9	7.6	2.7
38	Puerto Rican	Puerto Rico	429	48.7	38.7	9.6	3.0
39	Russian	Leningrad	1,800	28.3	39.5	22.9	9.3
40	Scottish	Glasgow	456	47.6	38.4	9.0	5.0
41	Siamese	Bangkok	6,267	37.3	21.8	33.1	7.8
42	Swedish	Kopparberg	10,732	38.5	44.7	10.9	5.8
43	Ukrainian	Kharkov	310	36.4	38.4	21.6	3.6
44	USA Negro	Iowa	6,722	49.1	26.5	20.1	4.3
45	USA white	Rochester, New York	23,787	44.4	41.8	10.1	3.8
46	Welsh	North Wales	192	47.9	32.8	16.1	3.1
47	Yugoslavian	Yugoslavia	1,527	32.8	42.7	17.9	6.6

Contributors: (a) Levine, Philip, (b) Levine, Victor E., (c) Wiener, Alexander S.

References: [1] Boyd, W. C. 1939. Tabulae Biologicae 17:113. [2] Boyd, W. C. 1950. Genetics and the races of man. Little and Brown, Boston. [3] Mourant, A. E., A. C. Kopec, and K. Domaniewska-Sobczak. 1958. The ABO blood groups. Blackwell, Oxford. [4] Wiener, A. S. 1943. Blood groups and transfusion. Ed. 3. C. C. Thomas, Springfield, Ill.

Part II. M-N TYPES

	Population	Location	No. of Subjects	Frequency, % Type M	Type N	Type MN
	(A)	(B)	(C)	(D)	(E)	(F)
1	Ainu	Shizunai	504	17.9	31.9	50.2
	American Indian					
2	Blackfoot	Montana	95	54.7	5.3	40.0
3	Navaho	New Mexico	361	84.5	1.1	14.4
4	Pueblo	New Mexico	140	59.3	7.9	32.8
5	Ute	Utah	104	58.7	6.7	34.6
6	Armenian	Vicinity of Marash, Turkey	332	32.8	20.2	47.0
7	Australian aborigine	Australia	730	3.0	67.4	29.6
8	Basque	Spain	91	23.1	25.3	51.6
	Bedouin					
9	Iraqi	Vicinity of Baghdad	338	38.2	13.6	48.2
10	Rwala	Syrian Desert	208	57.5	5.8	36.7
11	Belgian	Liège	3,100	28.9	20.8	50.3
12	Chinese	Hong Kong	1,029	33.2	18.2	48.6
13	Danish	Copenhagen	2,023	29.1	21.4	49.5
14	Egyptian	Cairo	613	28.3	23.1	48.6
15	English	London	1,522	30.5	21.4	48.2
16	Eskimo	East Greenland	569	83.5	0.9	15.6
17		Southwest Greenland	1,063	66.2	2.9	31.0
18	Estonian	Estonia	310	34.8	15.5	49.7
19	Fijian	Fiji Islands	200	11.0	44.5	44.5
20	Filipino	Philippine Islands	382	25.9	23.8	50.3
21	Finnish	Finland	6,926	42.3	13.7	44.0
22	French	Paris	1,400	30.1	19.8	50.1
23	German	Germany	40,255	30.2	19.7	50.0
24	Hindu	India	300	42.7	10.7	46.7
25	Hungarian	Budapest	624	33.5	18.6	47.9
26	Irish	Dublin	399	30.0	23.3	46.7
27	Italian	Modena and Sicily	736	28.9	17.1	53.9
28	Japanese	Japan	7,551	29.0	21.1	49.9
29	Korean	Korea	836	27.9	20.8	51.4

continued

82. DISTRIBUTION OF BLOOD GROUPS AND TYPES IN VARIOUS POPULATIONS: MAN

Part II. M-N TYPES

	Population	Location	No. of Subjects	Frequency, %		
				Type M	Type N	Type MN
	(A)	(B)	(C)	(D)	(E)	(F)
30	Papuan	Papua	200	7.0	69.0	24.0
31	Polish	Poland	600	28.2	22.8	49.0
32	Russian	Leningrad	763	32.2	21.2	46.5
33	Scottish	Glasgow	456	35.0	17.1	47.9
34	Swedish	Sweden	1,200	36.1	16.9	47.0
35	Ukrainian	Kharkov	310	36.1	19.6	44.3
36	USA Negro	New York City	278	28.4	21.9	49.6
37	USA white	New York City; Boston; Columbus, Ohio	6,129	29.2	21.3	49.6
38	Welsh	North Wales	192	30.7	14.0	55.3
39	Yugoslavian	Yugoslavia	1,527	30.3	17.9	51.8

Contributors: (a) Levine, Philip, (b) Wiener, Alexander S., (c) Levine, Victor E.

References: [1] Boyd, W. C. 1939. Tabulae Biologicae 17:113. [2] Boyd, W. C. 1950. Genetics and the races of man. Little and Brown, Boston. [3] Wicner, A. S. 1943. Blood groups and transfusion. Ed. 3. C. C. Thomas, Springfield, Ill.

Part III. Rh-Hr TYPES

	Population	No. of Subjects	Rh Positive Frequency, %						Rh Negative Frequency, %				Reference
			Rh_o	Rh_1: Rh_1Rh_1	Rh_1: Rh_1rh	Rh_2	Rh_1Rh_2	Rh_1Rh_z	rh	rh'	rh''	rh'rh''	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)
	American Indian												
1	In Mexico	95	1.1	40.7	7.4	9.5	38.1	3.1	0	0	0	0	5
2	In Oklahoma	105	2.9	34.3	5.7	17.1	36.2	2.9	0	0.9	0	0	5
3	Ute	104	0	33.7		28.8	37.5	...	0	0	0	0	1
4	Asiatic Indian	156	1.9	70.5		5.1	12.8	...	7.1	2.6	0	0	5
5	Australian aborigine	100	4.0	39.0	14.0	21.0	15.0	6.0	0	1.0	0	0	5
6	Australian white	350	0.6	54.0		12.6	16.6	...	14.9	0.9	0.6	0	5
7	Basque	167	0.6	7.8	47.3	7.8	6.0	0	28.8	1.8	0	0	3
8	Chinese	132	0.9	60.6		3.0	34.1	...	1.5	0	0	0	5
9	Dutch	200	1.5	51.5		12.3	17.7	...	15.4	1.5	0	0	5
10	Egyptian	...	11.5	25.5	39.7	9.2	8.2	...	5.9	...	...	....	4
11	English	927	2.5	19.7	35.2	12.2	13.6	0.1	14.8	0.7	1.3	0	5
12	Eskimo	315	1.0	34.9		19.7	44.4	...	0	0	0	0	2
13	Filipino	100	0	87.0		2.0	11.0	...	0	0	0	0	5
14	German	...	2.0	19.5	35.6	13.0	13.9	0.4	14.4	0.5	0.8	....	4
15	Hindu	...	2.9	35.2	32.4	3.8	16.2	0	7.6	1.9	...	....	4
16	Indonesian	200	0.5	74.0		2.5	22.5	0	0	0	0	0.5	5
17	Italian	...	1.3	23.3	37.3	9.6	11.8	0.7	14.8	0.5	0.5	0.3	4
18	Japanese	150	0	37.4		13.3	47.3	...	1.3	0	0	0.7	5
19	Norwegian	...	1.5	15.9	35.6	13.8	14.7	...	16.2	0.7	1.2	....	4
20	Papuan	100	0	89.0	4.0	0	4.0	3.0	0	0	0	0	5
21	Puerto Rican	179	15.1	39.1		19.6	14.0	...	10.1	1.7	0.5	0	5
22	USA Negro	135	45.9	0.9	22.8	16.3	4.4	0	7.4	1.5	0.7	0	5
23		223	41.2	20.2		22.4	5.4	...	8.1	2.7	0	0	5
24	USA white	766	2.2	20.9	33.8	14.9	13.9	0.1	12.5	0.9	0.5	0	5
25		7,317	2.2	53.5		15.0	12.9	...	14.7	1.1	0.6	0.01	5

Contributors: (a) Wiener, Alexander S., (b) Levine, Philip

References: [1] Matson, G. A., and C. L. Piper. 1947. Am. J. Phys. Anthropol. 5:357. [2] Matson, G. A., and H. J. Roberts. 1949. Ibid. 7:109. [3] Mourant, A. E. 1947. Nature 160:505. [4] Mourant, A. E. 1954. The distribution of the human blood groups. C. C. Thomas, Springfield, Ill. [5] Wiener, A. S. 1946. Am. J. Clin. Pathol. 16:477.

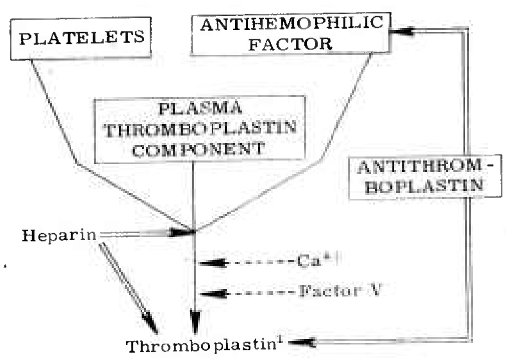
83. BLOOD COAGULATION THEORIES

Part I. ACCORDING TO F. C. MONKHOUSE AND W. W. COON (1963)

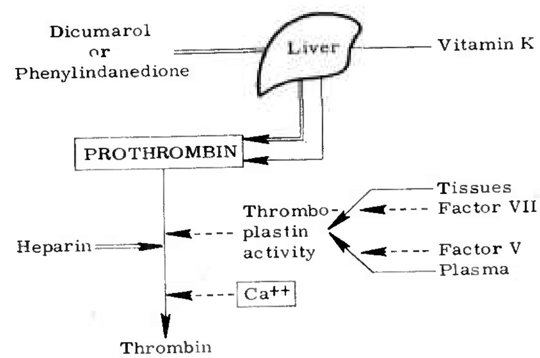
Synonymous terms for clotting factors: PLASMA THROMBOPLASTIN COMPONENT = Christmas factor, platelet cofactor-2, autoprothrombin-2; ANTIHEMOPHILIC FACTOR = antihemophilic globulin, thromboplastinogen; FACTOR V = Ac-globulin, labile factor, proaccelerin; FACTOR VII = stable factor, autoprothrombin-1, proconvertin, cothromboplastin; PLASMINOGEN = profibrinolysin; PLASMIN = fibrinolysin.

Symbols: ——► gives rise to; - - - -► acts on; ══► inhibits or destroys; ☐ present in blood.

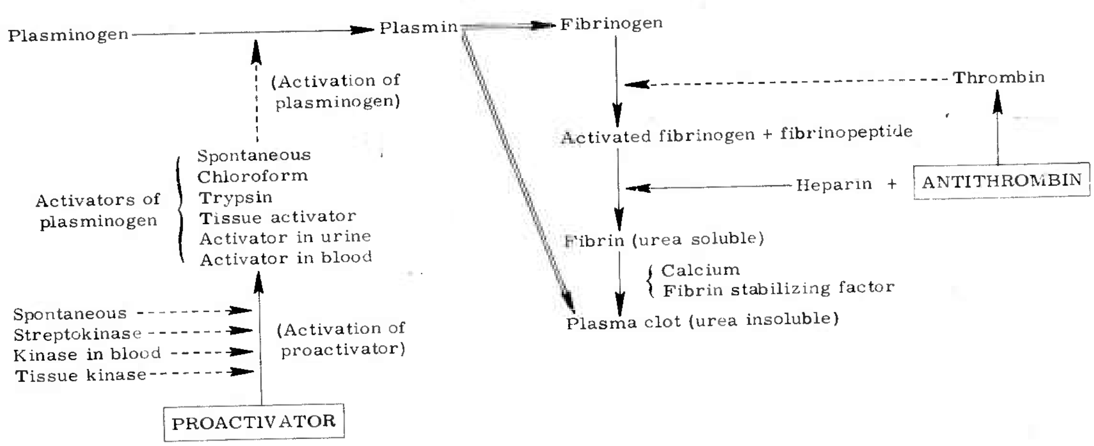
Stage I: Formation of Plasma Thromboplastin



Stage II: Formation of Thrombin



Stage III: Change of Fibrinogen to Fibrin



/1/ Other trace proteins affect the development of thromboplastin activity in plasma. Factor XII (Hageman factor) is sensitive to surface activation; its deficiency results in prolonged clotting time but no increase in bleeding time. The exact point of action of Factor X (Stuart-Prower factor) has not yet been determined.

Contributors: (a) Monkhouse, Frank C., (b) Coon, William W.

References: [1] Astrup, T. 1956. Blood 11:781. [2] Lorand, L. 1954. Physiol. Rev. 34:742. [3] Sherry, S., W. Troll, and H. Glueck. 1954. Ibid. 34:736.

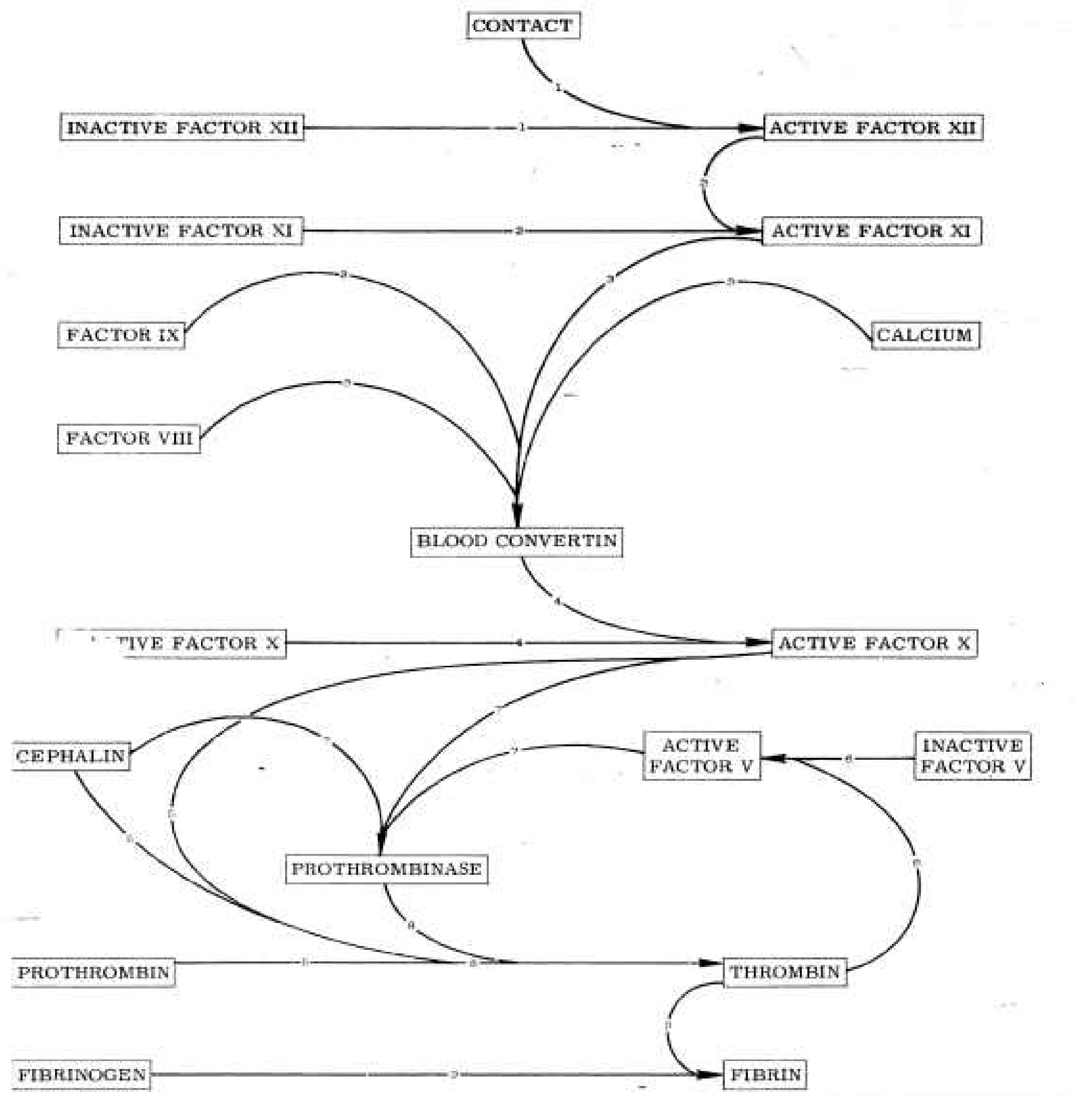
continued

83. BLOOD COAGULATION THEORIES

Part II. ACCORDING TO P. A. OWREN (1963)

System I: Intrinsic Blood Coagulation

Factor VII (proconvertin) does not take part in the intrinsic blood coagulation system.



/1/ CONTACT activates INACTIVE FACTOR XII (Hageman factor) to ACTIVE FACTOR XII. /2/ ACTIVE FACTOR XII activates INACTIVE FACTOR XI (plasma thromboplastin antecedent, PTA) to ACTIVE FACTOR XI. /3/ ACTIVE FACTOR XI, FACTOR IX (antihemophilia B factor, Christmas factor), FACTOR VIII (antihemophilia A factor, antihemophilic globulin), and CALCIUM interact to form BLOOD CONVERTIN. /4/ BLOOD CONVERTIN activates INACTIVE FACTOR X (Stuart-Prower factor) to ACTIVE FACTOR X. /5/ ACTIVE FACTOR X and CEPHALIN in the presence of calcium bring about a minimal conversion of PROTHROMBIN to THROMBIN. /6/ This initially formed THROMBIN starts the accelerator system, i.e., the conversion of INACTIVE FACTOR V (proaccelerin) to ACTIVE FACTOR V (accelerin). /7/ ACTIVE FACTOR X, ACTIVE FACTOR V, and CEPHALIN interact in the presence of calcium to form PROTHROMBINASE. /8/ PROTHROMBINASE produces rapid conversion of PROTHROMBIN to THROMBIN. /9/ THROMBIN is now formed in sufficient quantities to convert FIBRINOGEN to FIBRIN.

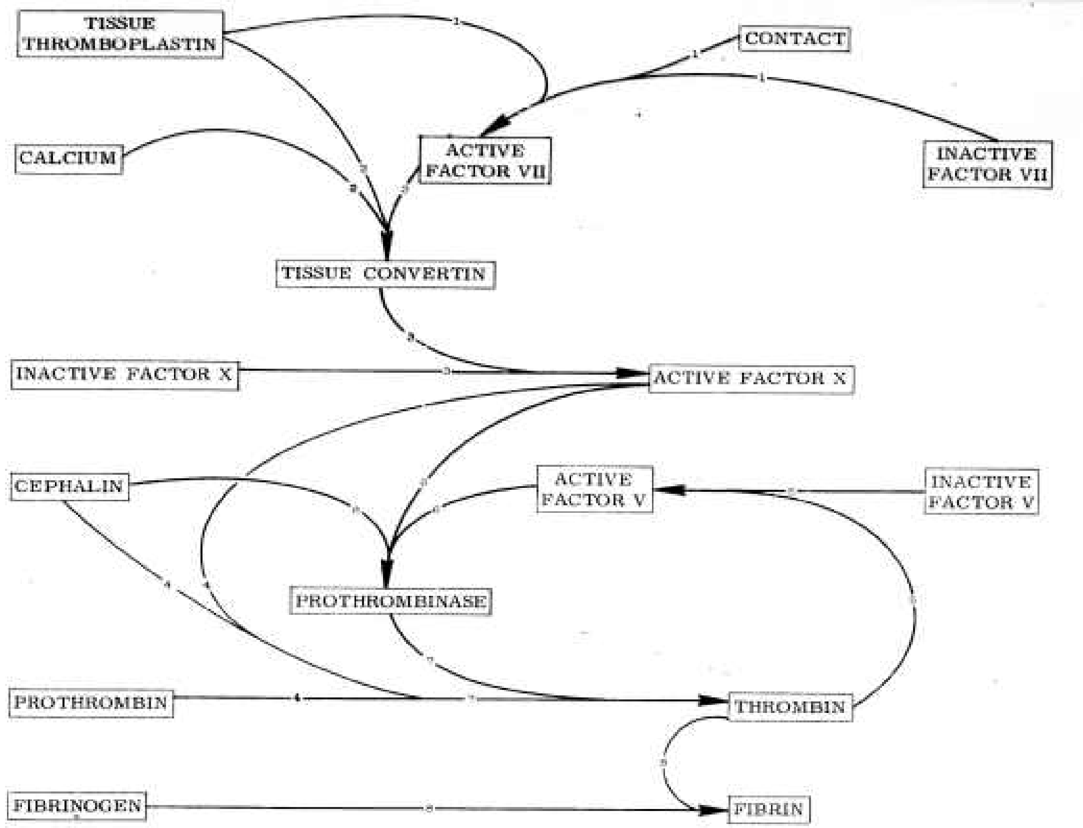
continued

83. BLOOD COAGULATION THORIES

Part II. ACCORDING TO P. A. OWREN (1963)

System II: Extrinsic (tissue-blood) Coagulation

Platelets and antihemophilic factors do not take part in the extrinsic blood coagulation system.



/1/ CONTACT (mediated through activation of factors XII and XI) and/or TISSUE THROMBOPLASTIN activates INACTIVE FACTOR VII (proconvertin) to ACTIVE FACTOR VII. /2/ TISSUE THROMBOPLASTIN (liberated by tissue injury), ACTIVE FACTOR VII, and CALCIUM interact to form TISSUE CONVERTIN. /3/ TISSUE CONVERTIN activates INACTIVE FACTOR X (Stuart-Prower factor) to ACTIVE FACTOR X. /4/ ACTIVE FACTOR X and CEPHALIN in the presence of calcium bring about a minimal conversion of PROTHROMBIN to THROMBIN. /5/ This initially formed THROMBIN starts the accelerator system, i.e., the conversion of INACTIVE FACTOR V (proaccelerin) to ACTIVE FACTOR V. /6/ ACTIVE FACTOR X, ACTIVE FACTOR V, and CEPHALIN interact in the presence of calcium to form PROTHROMBINASE. /7/ PROTHROMBINASE produces rapid conversion of PROTHROMBIN to THROMBIN. /8/ THROMBIN is now formed in sufficient quantities to convert FIBRINOGEN to FIBRIN.

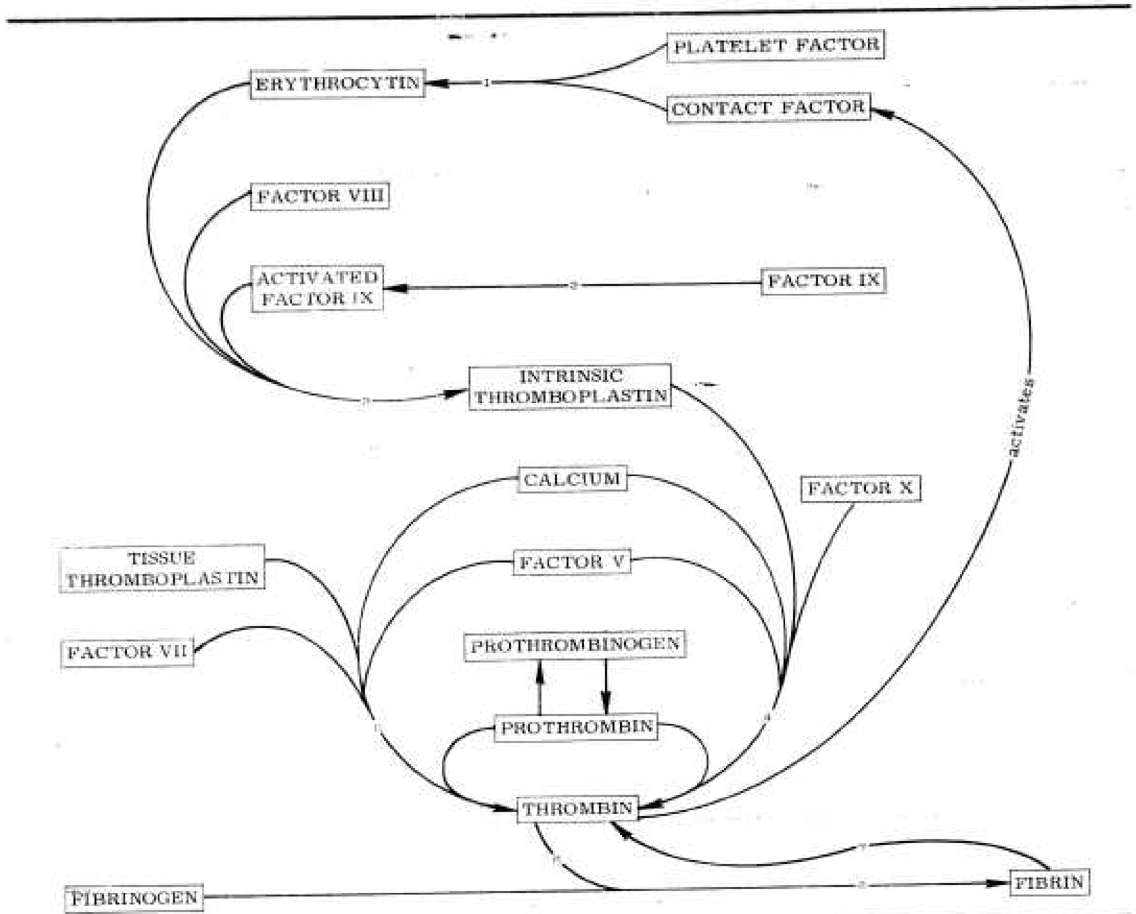
Contributor: Owren, Paul A.

References: [1] Hjort, P. F. 1957. Scand. J. Clin. Lab. Invest., Suppl. 27. [2] Owren, P. A. 1947. Acta Med. Scand., Suppl. 194. [3] Waaler, B. A. 1959. Scand. J. Clin. Lab. Invest., Suppl. 37.

continued

83. BLOOD COAGULATION THEORIES

Part III. ACCORDING TO A. J. QUICK (1963)



/1/ A plasma constituent, tentatively named CONTACT FACTOR, after activation by thrombin or by contact with glass, reacts with a PLATELET FACTOR to form ERYTHROCYTIN. /2/ FACTOR IX (plasma thromboplastin component) is inactive in plasma but is activated during coagulation. The activator mechanism is not known. /3/ ERYTHROCYTIN, FACTOR VIII (thromboplastinogen), and ACTIVATED FACTOR IX (activated plasma thromboplastin component) interact to form INTRINSIC THROMBOPLASTIN. /4/ INTRINSIC THROMBOPLASTIN, CALCIUM, FACTOR V (labile factor), and possibly FACTOR X (Stuart-Prower factor) interact with PROTHROMBIN to form THROMBIN. In human blood, a large fraction of prothrombin is inactive but becomes activated during coagulation in glass. /5/ When TISSUE THROMBOPLASTIN is utilized, FACTOR VII (stable factor) is required in addition to CALCIUM and FACTOR V. /6/ THROMBIN acts enzymatically on FIBRINOGEN to convert it to FIBRIN. /7/ The prompt removal of THROMBIN by adsorption on FIBRIN holds in check the autocatalytic reaction mediated through the activation of THROMBIN on the CONTACT FACTOR.

Contributor: Quick, Armand J.

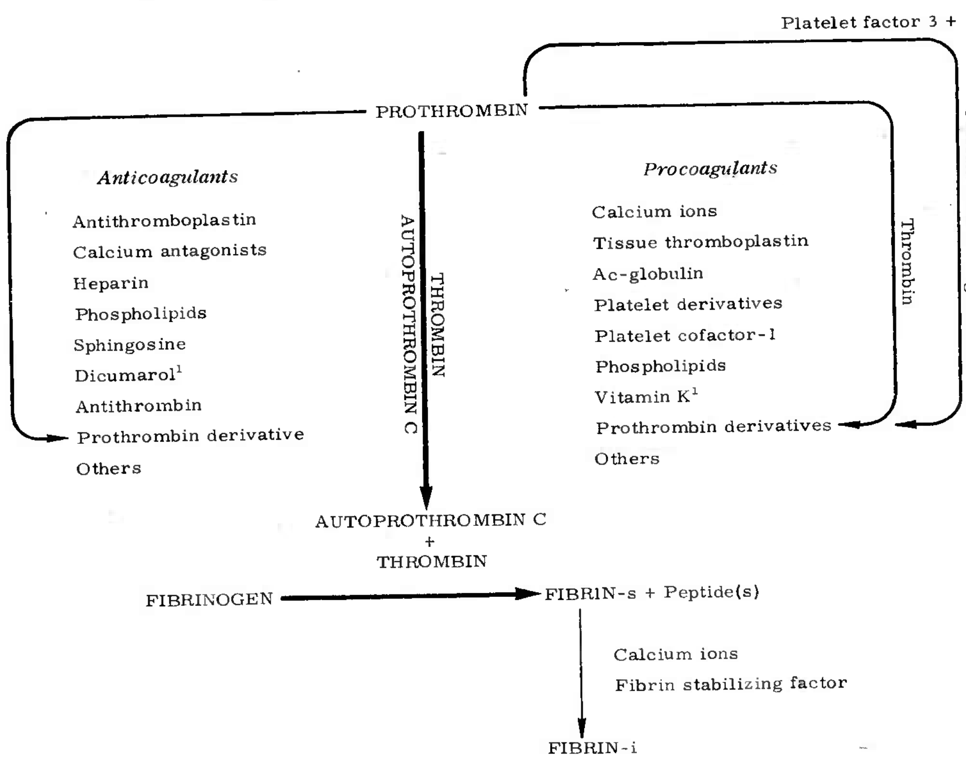
References: [1] Quick, A. J. 1943. Am. J. Physiol. 140:212. [2] Quick, A. J. 1947. Am. J. Med. Sci. 214:272. [3] Quick, A. J. 1958. Thromb. Diath. Haemorrhag. 2:226. [4] Quick, A. J. 1960. Am. J. Med. Sci. 239:51. [5] Quick, A. J. 1961. Ann. Internal Med. 55:201. [6] Quick, A. J., and J. E. Favre-Gilly. 1949. Am. J. Physiol. 158:387. [7] Quick, A. J., and C. V. Hussey. 1955. Brit. Med. J. 1:934.

continued

83. BLOOD COAGULATION THEORIES

Part IV. ACCORDING TO W. H. SEEGERS (1963)

Prothrombin is found in the blood and may become activated in the presence of one or more procoagulants. Since prothrombin itself contains all the necessary material for the formation of thrombin, purified prothrombin can be activated to thrombin and autoprothrombin C by placing it in 25% sodium citrate solution. Consequently the activators of prothrombin are catalysts and do not enter into stoichiometric combination with prothrombin to form thrombin. Anticoagulants inhibit the activation. Ordinarily the procoagulants and anticoagulants are present in balanced proportion. This balance is readily disturbed by the procoagulants from injured tissues. Contact with foreign surfaces also promotes prothrombin activation and platelet disintegration. With certain combinations of procoagulants, prothrombin is only partially activated, and these derivatives of prothrombin themselves accelerate the conversion of prothrombin to thrombin. Thrombin functions as activator of prothrombin, and a second enzyme from prothrombin, called autoprothrombin C, functions similarly. Prothrombin activation is primarily by autocatalysis. Thrombin also functions with accelerator systems, such as plasma Ac-globulin which becomes serum Ac-globulin, and it further supports the dissolution of platelets. Plasma antithrombin eventually destroys thrombin activity. By proteolysis, thrombin splits peptides from fibrinogen and acts as a polymerase in the polymerization of the activated fibrinogen. In the presence of calcium ions and fibrin stabilizing factor, the fibrin of a normal clot forms. Vitamin K is needed for the metabolic production of prothrombin and its derivatives, whereas dicumarol may interfere with normal prothrombin metabolism.



/1/ Related to prothrombin production.

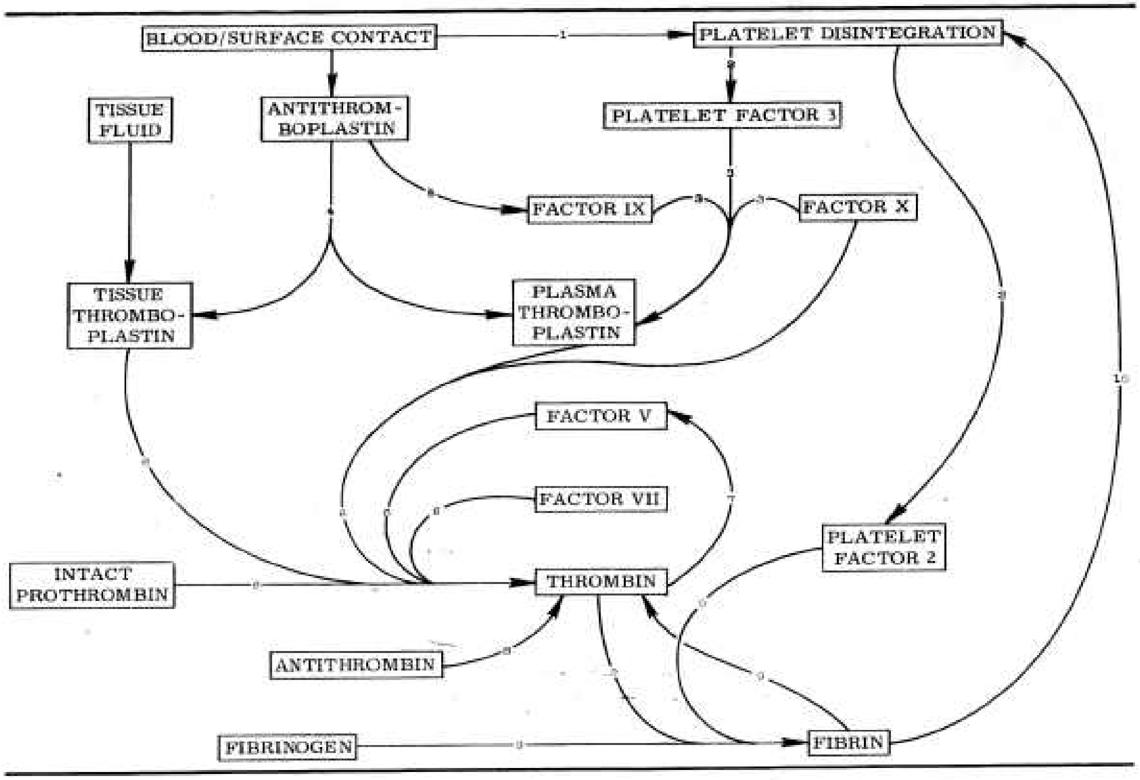
Contributor: Seegers, Walter H.

References: [1] McClaughry, R. I., and J. L. Fahey. 1950. Blood 5:421. [2] Milstone, J. H. 1948. Proc. Soc. Exptl. Biol. 68:225. [3] Seegers, W. H. 1950. Circulation 1:2. [4] Seegers, W. H. In J. B. Sumner and K. Myrbäck, ed. 1951. The enzymes. Academic Press, New York. v. 1, pt. 2, p. 1006. [5] Seegers, W. H., et al. 1963. Can. J. Biochem. Physiol. 41:1047. [6] Ware, A. G., J. L. Fahey, and W. H. Seegers. 1948. Am. J. Physiol. 154:140. [7] Ware, A. G., and W. H. Seegers. 1948. Ibid. 152:567.

continued

83. BLOOD COAGULATION THEORIES

Part V. ACCORDING TO L. M. TOCANTINS (1960)



/1/ CONTACT of BLOOD with certain SURFACES (damaged blood vessel endothelium, glass) initiates the first changes in the inception of clotting. Blood PLATELETS adhere to the surface and to each other, swell and DISINTEGRATE. /2/ PLATELET DISINTEGRATION releases, among other substances, PLATELET FACTOR 3 (cephalin-like factor) and PLATELET FACTOR 2 (a fibrinoplastic factor). /3/ Conjugation of PLATELET FACTOR 3 with FACTOR IX (platelet cofactor in plasma, plasma thromboplastin component) leads, with the aid of FACTOR X (Stuart-Prower factor), to formation of PLASMA THROMBOPLASTIN. /4/ Plasma ANTITHROMBOPLASTIN slows or blocks formation of THROMBOPLASTIN and, less effectively, offsets the action of formed THROMBOPLASTIN. Antihemophilic globulin is considered to represent various stages of development of plasma thromboplastin, or various degrees of conjugation of the platelet lipid and its plasma cofactor. /5/ Plasma ANTITHROMBOPLASTIN is probably a lipid in conjugation with FACTOR IX. /6/ THROMBOPLASTIN (from TISSUES, or generated in PLASMA) brings about, with the aid of FACTOR V (Ac-globulin) and FACTOR VII (convertin), a minimal amount of conversion of PROTHROMBIN to THROMBIN. /7/ This initial THROMBIN activates further transformation of PROTHROMBIN to THROMBIN, with the help of FACTOR V. /8/ Some of the THROMBIN may be inactivated by ANTITHROMBIN. /9/ The THROMBIN that escapes such inactivation acts, with the aid of PLATELET FACTOR 2, to convert FIBRINOGEN to FIBRIN. Some of the THROMBIN is removed from the plasma by adsorption on FIBRIN. /10/ Adhesion of platelets to FIBRIN probably causes further PLATELET DISINTEGRATION.

Contributor: Tocantins, Leandro M.

References: [1] Silver, M. J., D. L. Turner, and L. M. Tocantins. In L. M. Tocantins, ed. 1959. Progress in hematology. Grune and Stratton, New York. v. 2. [2] Tocantins, L. M. 1943. Am. J. Physiol. 139:265. [3] Tocantins, L. M. 1944. Proc. Soc. Exptl. Biol. Med. 55:291. [4] Tocantins, L. M. 1944. Ibid. 57:211. [5] Tocantins, L. M. 1946. Blood 1:56. [6] Tocantins, L. M. 1949. Surg. Clin. North Am. 29:1835. [7] Tocantins, L. M. 1954. Blood 9:281. [8] Tocantins, L. M. 1955. The coagulation of blood: methods of study. Grune and Stratton, New York. [9] Tocantins, L. M., R. T. Carroll, and R. R. Holburn. 1951. Blood 6:720. [10] Tocantins, L. M., R. T. Carroll, and T. J. MacBride. 1948. Proc. Soc. Exptl. Biol. Med. 68:110. [11] Tocantins, L. M., R. R. Holburn, and R. T. Carroll. 1951. Ibid. 76:623.

84. ACID-BASE BALANCE

For additional information, consult reference 2, Part I. *Abbreviations:* pK'_1 = first dissociation constant; f_{CO_2} = carbon dioxide factor.

Part I. ACID-BASE VALUES: MAN

Blood (column C): C = cutaneous; A = arterial; V = venous. Values in parentheses are ranges, estimate "b" (cf. Introduction).

	Subjects: Age	Subjects: No. and Sex	Blood	pH at 37°C	Hemoglobin[1] mM/L	CO_2 Content, mM/L: Whole Blood	CO_2 Content, mM/L: Plasma	CO_2 Pressure[2] mm Hg	Buffer-Base[3] mEq/L	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
1	4-6 da[4]	18♂♀	C	7.38(7.26-7.50)	10 (8.6-11.4)	15.3(11-20)	19(14.5-23.5)	31.1(23-40)	42.3(36-49)	6
2	3-15 yr	20♂♀	A	7.38	7.6	21.2	25	39.8	45.7	3,4
3	18-28 yr[5]	8♂	C	7.37(7.32-7.42)	9.3[6]	21.9(21.1-22.7)	26.8	43.5(37.9-49.1)	48.1	5
4		7♀	C	7.39(7.36-7.42)	7.6[6]	21.9(19.9-23.9)	26	40.4(37.5-43.3)	46.9	
5	24-43 yr	3♀	A	7.43	8.1[7]		25.9	38.4	47	1
6	Adult	259♂	A	7.39(7.34-7.44)	8.9 (7.7-10.3)	22.2(20-24)	26.9(25-29)	41.6(35-47)	48.4(46-52)	2
7		118♂	V	7.35(7.28-7.42)	8.9[8]	24.4(21-28)	29.6(26-33)	50	48.4[8]	

/1/ Hemoglobin concentration assumed to be 20 mM/L erythrocytes; 1 mM (single Fe-atom structure, molecular weight 16,500) combines with 22.4 ml of oxygen STP when saturated. /2/ CO_2 pressure calculated from adjusted pH and plasma CO_2 content by the Henderson-Hasselbalch equation ($pH - pK'_1 = \log \frac{CO_2 - 0.0314\ CO_2\ pressure}{0.0314\ CO_2\ pressure}$). /3/ Calculated from pH, bicarbonate, and other blood buffers, as described in reference 7. /4/ Formula-fed infants; different results were obtained with breast-fed infants. /5/ Observations made in the morning on fasting, seated subjects, after one-half hour rest. /6/ Calculated from hematocrit value. /7/ Average value for non-pregnant females [2]. /8/ Assumed equal to value in arterial blood.

Contributors: Singer, Richard B., and Hastings, A. Baird.

References: [1] Alexander, J. K., et al. 1955. J. Clin. Invest. 34:511. [2] Altman, P. L., and D. S. Dittmer, ed. 1961. Blood and other body fluids. Federation of American Societies for Experimental Biology, Washington, D. C. [3] Kennedy, C., and L. Sokoloff. 1957. J. Clin. Invest. 36:1130. [4] Robinson, S. 1938. Arbeitsphysiologie 10:251. [5] Shock, N. W., and A. B. Hastings. 1934. J. Biol. Chem. 104:585. [6] Singer, R. B. Unpublished. New England Mutual Life Insurance Co., Boston, 1958. [7] Singer, R. B., and A. B. Hastings. 1948. Medicine 27:223.

Part II. ACID-BASE VALUES: VERTEBRATES

pH adjusted to body temperature by applying correction of -0.015 per °C temperature difference. CO_2 pressure calculated by means of Henderson-Hasselbalch equation; value of pK'_1 increases 0.005 per °C decrease in temperature, and f_{CO_2} is assumed to increase proportionately as it does in pure water. The following values for pK'_1 and f_{CO_2} were used for body temperatures other than 38°C: 5°C, 6.26 and 0.0864; 10°C, 6.24 and 0.0697; 20°C, 6.19 and 0.0508; 26°C, 6.16 and 0.0434; 34°C, 6.12 and 0.0357; 40°C, 6.09 and 0.0313; 42°C, 6.08 and 0.0303. **Blood** (column B): A = arterial; M = mixed arterial and venous; V = venous; H = heart. Values in parentheses are ranges, estimate "c" unless otherwise indicated (cf. Introduction).

	Species (Common Name)	Body Temp. °C (Blood)	Whole Blood pH	Erythrocytes: Hb mM/L	Erythrocytes: Vol %	Plasma: CO_2 Content mM/L	Plasma: CO_2 Pressure mm Hg	Plasma: Na^+ mEq/L	Plasma: Cl^- mEq/L	Plasma: H_2O g/L	Plasma: Protein g/L	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
	Mammalia and Aves[1]											
1	*Homo sapiens* (man), adult♂	37 (A)	7.39 $(7.33-7.45)^b$	9.0	45	27.0 $(25-29)^b$	42 $(36-47)^b$	138 $(132-144)^b$	102 $(97-108)^b$	940	68	B,C,F-I,2; D,E,J,K,15
2	*Bos taurus* (cattle), ♀	38.5 (A)	7.38 $(7.27-7.49)^b$	7.0	40	31.0 $(29-33)^b$	50	142 $(132-152)^b$	104 $(97-111)^b$	930[2]	83	B,16;C,F-I, 26;D,E,K, 2;J,28

/1/ Homoiothermic body temperature relatively independent of environmental temperature except in hibernating animals. /2/ Calculated data.

continued

84. ACID-BASE BALANCE

Part II. ACID-BASE VALUES: VERTEBRATES

	Species (Common Name)	Body Temp. °C (Blood)	Whole Blood pH	Erythrocytes: Hb mM/L	Erythrocytes: Vol %	Plasma: CO_2 Content mM/L	Plasma: CO_2 Pressure mm Hg	Plasma: Na^+ mEq/L	Plasma: Cl^- mEq/L	Plasma: H_2O g/L	Plasma: Protein g/L	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
	Mammalia and Aves[1]											
3	*Canis familiaris* (dog)	38.9 (A)	7.36 (7.31-7.42)	9.0	46	21.4 (17-24)	38	147 (140-154)[b]	114 (108-119)[b]	941	67	B,14;C,F,G, 4,14,19;D, E,K,2;H-J, 27
4	*Cavia* sp. (guinea pig)	38.6 (H; A)	7.35 (7.17-7.55)	8.7	42	22.0 (16-26)[3]	40 (19-59)	141 (138-144)	104 (100-108)	954[2]	47	B,C,F,G,21; D,E,K,2;H, I,22;J,28
5	*Equus caballus* (horse)	37.8 (V)	(7.20-7.55)	6.8	33	28.1 (24-32)	47[3]	135	96	931	68	B,C,16;D,E, K,2;F,23; G,28;H-J, 30
6	*Felis catus* (cat)	38.6 (M)	7.35 (7.24-7.40)			20.4 (17-24)[b]	36	153 (150-156)[b]	120 (117-123)[b]	941		B,16,34; C-J,34
7	Anesthetized	38.6 (V)	7.28 (7.18-7.35)	6.8	40	21.8 (19-25)	45 (34-52)		108 (105-111)	942	76	B,16,32;C, F-J,32;D, E,K,2
8	*Gallus domesticus* (chicken)	41.7 (V)	7.54 (7.45-7.63)	6.8	32	23.0 (21-26)	26[3]	154 (148-161)	117 (109-120)	960[2]	36	B,16;C,24; D,E,K,2;F, 1;G,J,28; H,I,22
	Mesocricetus auratus (golden hamster)											
9	Anesthetized	38 (H; V)	7.39 (7.37-7.44)	8.4	46	37.3 (35-39)	59 (54-61)	144 (140-151)	106 (103-108)	945[2]		B,C,F,G,25; D,E,2;H,I, 22;J,28
10	Hibernating	5 (H; V)	7.44 (7.34-7.56)			42.4 (35-50)	32 (26-42)					25
11	*Oryctolagus cuniculus* (European rabbit)	39.4 (A)	7.35 (7.21-7.57)	7.2		22.8 (13-33)[3]	40 (22-51)	140 (139-142)	102 (99-105)	944[2]		B,16,21;C, F,G,21,35; D,H,I,35; J,28
12	*Ovis aries* (sheep)	39.1 (V)	7.44 (7.32-7.54)	7.6	32	26.2 (21-28)	38	153 (146-161)	103 (98-109)	947[2]	57	B,16;C,F-I, 9;D,E,K,2; J,28
13	*Rattus* sp. (rat)	38.2 (A)	7.35 (7.26-7.44)[b]	9.0	46	24.0 (20-28)[b]	42	144 (135-155)[b]	104 (99-112)[b]	946	60	B,5,6,21;C, F-I,5,6;D, E,K,2;J,6
	Reptilia, Pisces, and Chondrichthyes[4]											
14	*Alligator mississipiensis*	34 (H; M)	7.43	5.4		19.8	29		105	954[2]	46	B-I,K,12;J, 28
15	(American alligator)[5]	26 (H; M)	7.48 (7.33-7.62)	4.3	22	23.5 (15-40)	38	141 (136-143)	112 (106-117)	952[2]	50	B-I,K,7;J, 28
16		5 (H; M)	7.74	4.2	25	36.1	15		110	958[2]	41	B-I,K,12;J, 28
17	*Anolis carolinensis* (American "chameleon")	26 (H; M)	7.26 (6.93-7.63)	4.2	28	15.4 (10-22)	27	157 (139-186)	127 (113-133)	958[2]	41	B-I,K,10;J, 28

/1/ Homoiothermic body temperature relatively independent of environmental temperature except in hibernating animals. /2/ Calculated data. /3/ Calculated from whole blood CO_2 content, pH, and hemoglobin, by means of nomogram of Singer and Hastings [29]. /4/ Poikilothermic body temperature dependent on environmental temperature. When temperature is decreased, pH and CO_2 solubility coefficient increase, and the O_2 dissociation curve is shifted to the left. /5/ The alligator shows a marked variation among individuals and in the same individual at different seasons, and a prolonged and extreme "alkaline tide" following meals [8].

continued

Part II. ACID-BASE VALUES: VERTEBRATES

	Species (Common Name)	Body Temp. °C (Blood)	Whole Blood pH	Erythrocytes		Plasma						Reference
				Hb mM/L	Vol %	CO_2 Content mM/L	CO_2 Pressure mm Hg	Na^+ mEq/L	Cl^- mEq/L	H_2O g/L	Protein g/L	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
	Reptilia, Pisces, and Chondrichthyes[4]											
18	*Cyprinus carpio* (carp)	20[3] (H; V)	7.39 (7.33-7.45)	6.4	31	17.7 (14-22)	22[3]	130 (126-137)	107 (96-121)	957[3]	42	B,G,J,28;C, F,3;D,E,H, K,18;I,31
19		15 (V)			39	13.5[6]	8.5[6]		147	951		17
20	*Pseudemys scripta elegans* (red-eared turtle)	26 (H)	7.65 (7.50-8.10)		25	24.4 (18-32)		125 (114-135)	92 (80-100)			33
21	*Raja* sp. (skate)	10.4 (A)	7.82	2.7	20	3.5	1.3	254 (219-289)	255 (230-285)	967[3]	27	B-G,K,13;H, I,20;J,28
22	*Salmo gairdneri* (rainbow trout)	15 (V)			35	9.5[6]	9.0[6]		140	955		17
23	*Thamnophis* sp. (garter snake)	26 (H)	7.25 (7.12-7.50)		28	6.6 (3-16)		156 (143-169)	130 (122-143)		42	11

/3/ Calculated data. /4/ Poikilothermic body temperature dependent on environmental temperature. When temperature is decreased, pH and CO_2 solubility coefficient increase, and the O_2 dissociation curve is shifted to the left. /6/ Value for whole blood.

Contributors: (a) Singer, Richard B., (b) Irvin, J. Logan, (c) Hernandez, Thomas

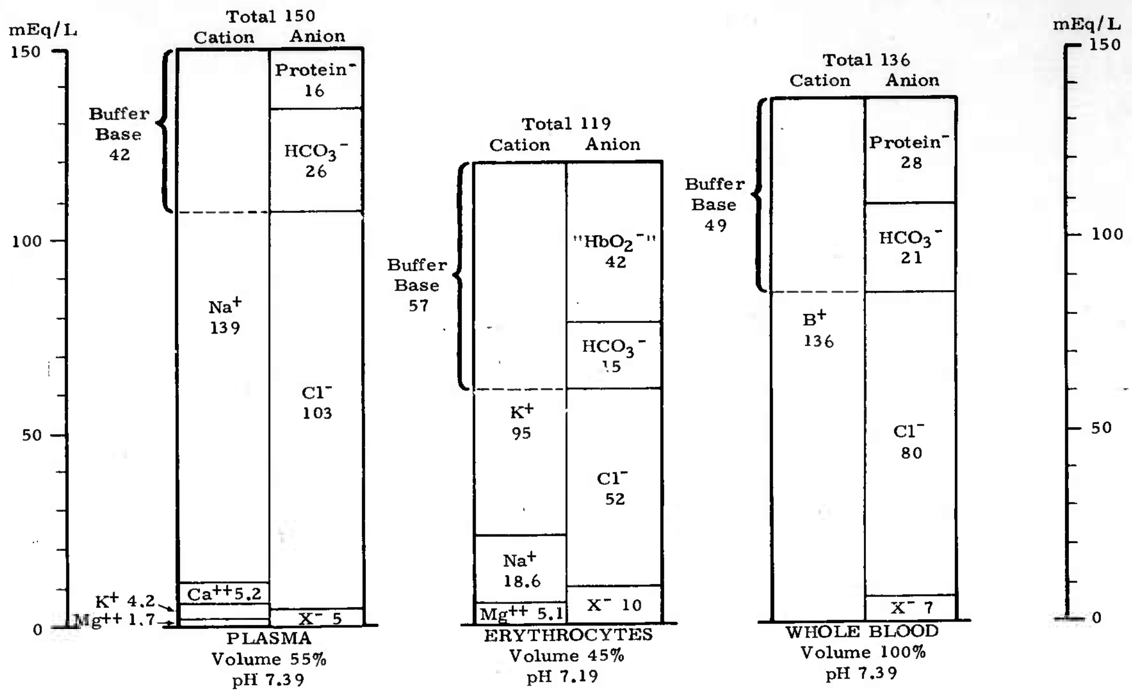
References: [1] Ackerson, C. W., M. J. Blish, and F. E. Mussehl. 1925. J. Biol. Chem. 63:75. [2] Albritton, E. C., ed. 1952. Standard values in blood. W. B. Saunders, Philadelphia. [3] Auvergnat, R., and M. Lecondat. 1942. Compt. Rend. 215:92. [4] Bennett, M. A. 1926. J. Biol. Chem. 69:675. [5] Cooke, R. E., F. R. Coughlin, Jr., and W. E. Segar. 1952. J. Clin. Invest. 31:1006. [6] Cotlove, E., et al. 1951. Am. J. Physiol. 167:665. [7] Coulson, R. A., and T. Hernandez. Unpublished. Louisiana State Univ., New Orleans, 1963. [8] Coulson, R. A., T. Hernandez, and H. C. Dessauer. 1950. Proc. Soc. Exptl. Biol. Med. 74:866. [9] Denton, D. A., et al. 1951. Acta Med. Scand., Suppl. 261. [10] Dessauer, H. C. 1952. Proc. Soc. Exptl. Biol. Med. 80:742. [11] Dessauer, H. C., and W. Fox. Unpublished. Louisiana State Univ., New Orleans, 1955. [12] Dill, D. B., and H. T. Edwards. 1935. J. Cellular Comp. Physiol. 6:243. [13] Dill, D. B., H. T. Edwards, and M. Florkin. 1932. Biol. Bull. 62:23. [14] Dill, D. B., et al. 1932. J. Biol. Chem. 95:143. [15] Dill, D. B., et al. 1940. Ibid. 136:449. [16] Dukes, H. H. 1955. The physiology of domestic animals. Ed. 7. Comstock, Ithaca. [17] Ferguson, J. K. W., and E. C. Black. 1941. Biol. Bull. 80:139. [18] Field, J. B., C. A. Elvehjem, and C. Juday. 1943. J. Biol. Chem. 148:261. [19] Harkins, H. N., and A. B. Hastings. 1931. Ibid. 90:565. [20] Hartman, F. A., et al. 1941. Physiol. Zool. 14:476. [21] Hawkins, J. A. 1924. J. Biol. Chem. 61:147. [22] Hernandez, T., and R. A. Coulson. Unpublished. Louisiana State Univ., New Orleans, 1955. [23] Ichiji, N. 1922. J. Japan. Soc. Vet. Sci. 1:76. [24] Johnson, E. P., and W. B. Bell. 1936. J. Infect. Diseases 58:342. [25] Lyman, C. P., and A. B. Hastings. 1951. Am. J. Physiol. 167:633. [26] McSherry, B. J., and I. Griner. 1954. Am. J. Vet. Res. 15:509. [27] Mellors, R. C., E. Muntwyler, and F. R. Mantz. 1942. J. Biol. Chem. 144:773. [28] Singer, R. B. Unpublished. New England Mutual Life Insurance Co., Boston, 1953. [29] Singer, R. B., and A. B. Hastings. 1948. Medicine 27:223. [30] Van Slyke, D. D., et al. 1925. J. Biol. Chem. 65:701. [31] Vars, H. M. 1934. Ibid. 105:135. [32] Wallace, W. M., and A. B. Hastings. 1942. Ibid. 144:637. [33] Williams, J. K. Unpublished, 1959. [34] Yannet, H. 1940. J. Biol. Chem. 136:265. [35] Young, I. M. 1952. Am. J. Physiol. 170:434.

continued

84. ACID-BASE BALANCE

Part III. NORMAL IONIC PATTERNS, ARTERIAL BLOOD: MAN

Values are for the adult male and are based on the literature. X^- = undetermined anion residue. "HbO_2^-" includes other erythrocyte buffer anions, such as organic phosphate. B^+ = mEq total cation (Na^+, K^+, etc.) in 1 liter of blood, on the basis of a hematocrit value of 45%. Buffer base = the appropriate fraction of total cations and its equivalent of total anions (labile fraction), i.e., proteinate, bicarbonate, oxyhemoglobinate, organic phosphate, and other erythrocyte buffer anions. CO_2 partial pressure or tension for plasma, erythrocytes, or whole blood = 41 mm Hg.



Contributor: Singer, Richard B.

Part IV. CLASSIFICATION OF ACID-BASE DISTURBANCES: MAN

Ranges for acid-base variables, as reported in the literature or inferred from related observations, are for adult arterial or cutaneous blood. *See also* normal values, Part I. Limits given are approximate. Boldface type (columns B and C) indicates the best index for existence of the particular condition.

	Condition	Buffer Base[1] mEq/L	CO_2 Pressure mm Hg	Bicarbonate[2] mEq/L	pH at 37°C
	(A)	(B)	(C)	(D)	(E)
1	Normal (arterial or cutaneous blood)	46-52	35-45	24-28	7.35-7.45
2	Metabolic acidosis (acid excess or base deficit)	**Always low** 20-46	Usually low 15-35	Usually low 4-24	Usually low 6.8-7.35

/1/ Buffer base for whole blood of normal hemoglobin concentration = 15 g/100 ml. A decrease in buffer base of whole blood is almost always accompanied by a decrease in plasma or extracellular Na^+ relative to $Cl^- + X^-$, e.g., decrease in plasma Na^+, increase in plasma Cl^- or plasma X^-, or any appropriate combination. An increase in buffer base of whole blood is accompanied by an increase in Na^+ relative to $Cl^- + X^-$, e.g., increase in plasma Na^+, decrease in plasma Cl^-, or any appropriate combination. *See* normal values in diagram, Part III. /2/ Comprises about 90-98% of total carbon dioxide in plasma; average, 95%.

continued

84. ACID-BASE BALANCE

Part IV. CLASSIFICATION OF ACID-BASE DISTURBANCES: MAN

	Condition	Buffer Base[1] mEq/L	CO_2 Pressure mm Hg	Bicarbonate[2] mEq/L	pH at 37°C
	(A)	(B)	(C)	(D)	(E)
3	Respiratory acidosis (H_2CO_3 excess)	Normal or high 46-70	**Always high** 45-100+	Usually high 28-45	Usually low 7.0-7.35
4	Metabolic alkalosis (base excess or acid deficit)	**Always high** 52-75	Normal or high 35-55	Usually high 28-50	Usually high 7.45-7.65
5	Respiratory alkalosis (H_2CO_3 deficit)	Normal or low 40-52	**Always low** 10-35	Usually low 15-24	Usually high 7.45-7.70
6	Mixed acidosis (combination of lines 2 and 3)	Always low 25-45	Always high 45-100	Variable 10-35	Always low 6.8-7.35
7	Mixed alkalosis (combination of lines 4 and 5)	Always high 52-70	Always low 15-35	Variable 20-45	Always high 7.5-7.7
8	Mixed hypercapnia (combination of lines 3 and 4)	Always high 52-75	Always high 45-100	Always high 30-50	Variable 7.3-7.6
9	Mixed hypocapnia (combination of lines 2 and 5)	Always low 20-46	Always low 10-35	Always low 4-22	Variable 7.0-7.6

/1/ Buffer base for whole blood of normal hemoglobin concentration = 15 g/100 ml. A decrease in buffer base of whole blood is almost always accompanied by a decrease in plasma or extracellular Na^+ relative to $Cl^- + X^-$, e.g., decrease in plasma Na^+, increase in plasma Cl^- or plasma X^-, or any appropriate combination. An increase in buffer base of whole blood is accompanied by an increase in Na^+ relative to $Cl^- + X^-$, e.g., increase in plasma Na^+, decrease in plasma Cl^-, or any appropriate combination. *See* normal values in diagram, Part III. /2/ Comprises about 90-98% of total carbon dioxide in plasma; average, 95%.

Contributor: Singer, Richard B.

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85. BLOOD VOLUMES

For additional information, consult reference 1, Part I.

Part I. VERTEBRATES

For a summary of blood methods and interpretations, consult reference 11. Subjects were normal, adult animals. Plasma and erythrocyte volumes were obtained by various dilution methods (diluent or tagging substance is given in the pertinent method column). Venous hematocrit values were obtained by centrifuging the blood sample (3,000 rpm, 30 minutes, 18 cm radius). In most instances, whole blood volume was calculated from other values in the same study; where a tagging substance is given in column H, blood volume was determined directly by dilution of the tagged erythrocytes in whole blood, on the assumption that the erythrocyte concentration in the sampled blood represented the total body erythrocyte concentration. **Method** (columns C, E, H): PV = plasma volume; EV = erythrocyte volume; VH = venous hematocrit; BV = whole blood volume. Values in parentheses are ranges, estimate "c" (cf. Introduction).

	Species (Common Name)	Subjects	Plasma Volume Method	Plasma Volume ml/kg body wt	Erythrocyte Volume Method	Erythrocyte Volume ml/kg body wt	Venous Hematocrit % cells	Whole Blood Volume Method	Whole Blood Volume ml/kg body wt	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Mammalia									
1	*Homo sapiens* (man)	25	T-1824	45.4 (32.3-54.2)	P^{32}	30.1 (21.1-44.1)		PV + EV	75.5 (60.9-95.8)	6
2		30♂	T-1824	41.1	P^{32}	28.0[1]		PV + EV	69.1	25
3		40♂	T-1824	47.9 (39.2-62.5)	Fe^{55} or Fe^{59}	29.8 (21.5-36.3)		PV + EV	77.7 (63.8-97.0)	10
4		20♂	T-1824	45.7 (35.8-56.5)			44.1 (39.3-49.4)	$\frac{PV}{100 - VH} \times 100$	81.6 (65.4-95.2)	30

/1/ Corrected for trapped plasma by factor of 0.96.

continued

85. BLOOD VOLUMES

Part I. VERTEBRATES

	Species (Common Name)	Subjects	Plasma Volume		Erythrocyte Volume		Venous Hematocrit % cells	Whole Blood Volume		Reference
			Method	ml/kg body wt	Method	ml/kg body wt		Method	ml/kg body wt	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Mammalia									
5	*Homo sapiens* (man)	30♀	T-1824	40.5	P^{32}	21.6[1]		PV + EV	63.1	25
6		20♀	T-1824	44.7 (37.2-58.5)			39.8 (37.1-41.9)	$\frac{PV}{100 - VH} \times 100$	74.3 (63.0-97.5)	30
7		35♀	T-1824	48.2 (37.7-57.2)			39.2 (34.5-43.8)[1]	$\frac{PV}{100 - VH} \times 100$	79.5 (65.0-99.8)	28
8	*Bos taurus* (cattle)	10♀	T-1824	38.8 (36.3-40.6)			32.4 (30.3-34.9)[2]	$\frac{PV}{100 - VH} \times 100$	57.4 (52.4-60.6)	23
9	*Camelus dromedarius* (Arabian camel)	19♂	T-1824	59 (47-70)			29	$\frac{PV}{100 - VH} \times 100$	83 (68-100)	3
10	*Canis familiaris* (dog)	11	T-1824	55.2 (43.7-73.0)	P^{32}	39.0 (28.0-55.0)	44 (35-54)[1]	PV + EV	94.1 (76.5-107.3)	27
11	*Capra hircus* (goat)	20	T-1824	55.9 (42.6-75.1)	Cr^{51}[3]	14.7 (9.7-19.3)	24.3 (18.5-30.8)[4]	PV + EV	70.5 (56.8-89.4)	18
12	*Cavia* sp. (guinea pig)	13	I^{131} rabbit globulin	39.4 (35.1-48.4)[5]				$\frac{PV}{100 - VH} \times 100$	75.3 (67.0-92.4)	19
13	*Didelphis* sp. (opossum)	10[6]	T-1824	37.8 (29.6-52.2)	P^{32}	19.2 (14.2-29.2)		PV + EV	57.0 (44.5-69.8)	7
	Equus caballus (horse)									
14	Light wt	6	BV - EV	61.9 (45.5-79.1)	P^{32}	47.1 (39.6-57.5)	43.3 (37-56)	$\frac{EV}{VH} \times 100$	109.6 (94.3-136.0)	16
15	Heavy wt	4	BV - EV	43.2 (30.6-64.1)	P^{32}	28.5 (23.1-37.6)	40.3 (37-46)	$\frac{EV}{VH} \times 100$	71.7 (56.7-101.7)	16
16	*Felis catus* (cat)	5♂[6]	T-1824	40.7 (34[illegible]52[illegible])	Cr^{51}[3]	14.8 (12.2-17.7)[1]		PV + EV	55.5 (47.3-65.7)	9
17	*Macaca mulatta* (rhesus monkey)	15♂, 3♀	T-1824	3[illegible].4 (30.0-48.4)	P^{32}	17.7 (14.3-20.0)	39.6 (35.6-42.8)[1]	PV + EV	54.1 (44.3-66.6)	12
18	*Mus* sp. (mouse)	11	T-1824	48.8	P^{32}	29.0		PV + EV	77.8	32
19	*Myotis lucifugus* (little brown bat)	123[6]	T-1824	65			49.3[7]	$\frac{PV}{100 - VH} \times 100$	130	17
20	*Oryctolagus cuniculus* (European rabbit)	29	T-1824	38.8 (27.8-51.4)	P^{32}	16.8 (13.7-25.5)		PV + EV	55.6 (44.0-70.0)	2
21		71			P^{32}	17.5 (13.4-22.8)	35.2 (28.6-41.0)[1]	$\frac{EV \times 100}{0.858(VH) - 0.2}$	57.3 (47.8-69.5)	2
22	*Ovis aries* (sheep)	5	T-1824	46.7 (43.4-52.9)	Cr^{51}[3]	19.7 (16.3-23.8)		PV + EV	66.4 (59.7-73.8)	14
23	*Rattus norvegicus* (Norway rat)		T-1824	40.4 (36.3-45.3)[8]	P^{32}	23.7 (18.4-26.0)[8]	50.3 (42.3-61.5)[6,9]	PV + EV	64.1 (57.5-69.9)[8]	31
	Sus scrofa (swine)									
24	45 kg	4			P^{32}	25.9 (20.2-29.0)	39.1 (30.3-43.1)[9]	$\frac{EV}{VH} \times 100$	65 (61-68)	13
25	50 kg	6[6]	BV - EV	41.9	$BV \times \frac{VH}{100}$	27.5		P^{32} erythrocytes	69.4	8
	Aves									
26	*Anas platyrhynchos domesticus* (Pekin duck)	42	I^{131} human serum albumin	65.5				$\frac{PV}{100 - VH} \times 100$	102	21
27		2♂			Cr^{51}[3]	30	38.5			24
28		2♀			Cr^{51}[3]	25	43.5			24

/1/ Corrected for trapped plasma by factor of 0.96. /2/ Corrected for trapped plasma by factor of 0.94. /3/ Cr^{51} as sodium chromate. /4/ Corrected for trapped plasma by factor of 0.81. /5/ Calculated from an average hematocrit of 47.6 obtained from 10 other guinea pigs. /6/ Anesthetized. /7/ Cardiac blood. /8/ Blood samples taken from carotid artery or tail vein. /9/ Corrected for trapped plasma by factor of 0.95.

continued

85. BLOOD VOLUMES

Part I. VERTEBRATES

	Species (Common Name)	Subjects	Plasma Volume		Erythrocyte Volume		Venous Hematocrit % cells	Whole Blood Volume		Reference
			Method	ml/kg body wt	Method	ml/kg body wt		Method	ml/kg body wt	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Aves									
29	*Columba livia* (street pigeon)	6	T-1824	44	Consult ref. 4	49	52	Consult ref. 4	92	5
30	*Gallus domesticus* (chicken)	110♂[11], 113♀[11]	T-1824					$\frac{PV}{100 - VH} \times 100$	90	20
31		3♂[12]	T-1824	31	Consult ref. 4	25	45	Consult ref. 4	56	5
32		4♀[12]	T-1824	44	Consult ref. 4	19	30	Consult ref. 4	63	5
33	*Phasianus colchicus* (ring-necked pheasant)	4♂	T-1824	45	Consult ref. 4	22	33	Consult ref. 4	67	5
34		2♀	T-1824	32	Consult ref. 4	16	34	Consult ref. 4	48	5
	Reptilia and Amphibia									
35	*Alligator mississipiensis* (American alligator)	16♂[6], 17♀[6]	I^{131}	60.1	Cr^{51}	12.6	22.7	PV + EV	72.7	15
36	*Pseudemys scripta elegans* (red-eared turtle)	26[13]	T-1824[14]	7[illegible].0 (58.2-90.8)			18.5 (12.0-25.4)	$\frac{PV}{100 - VH} \times 100$	90.8 (72.5-110.2)	26
37	*Rana catesbeiana* (American bullfrog)	2	T-1824	80[7]			15.5[7]		95	22
	Pisces and Chondrichthyes									
38	*Ictalurus natalis* (yellow bullhead)	6	T-1824	12.5[7]			30.1[7]		17.7	22
39	*Raja rhina* (longnose skate)	8[6]	T-1824	59 (34-79)			16.8 (12.0-21.5)[7,15]		72 (40-95)	29
40	*Squalus acanthias* (Atlantic spiny dogfish)	24[6]	T-1824	55 (25-90)			18.2 (14-24)[16]		68 (31-109)	29

/6/ Anesthetized. /7/ Cardiac blood. /11/ New Hampshires from 6 weeks old to maturity. /12/ White Leghorns. /13/ Unfed 3-8 weeks. /14/ And high-molecular-weight dextran. /15/ 11 subjects. /16/ 25 subjects.

Contributors: (a) Reynolds, Monica, (b) Brown, Ellen

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Part I. VERTEBRATES

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Part II. INSECTS

For additional information, consult reference 5. Hemolymph volume varies according to sex, stage of development, age, nutrition, rearing status, method of blood extraction, coagulability, and method of volume determination. Determinations were made on live or fresh-killed insects. Values in parentheses are ranges, estimate "b" or "c" as indicated (cf. Introduction).

	Species	Common Name	Stage	Method	Hemolymph Volume	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
1	*Aedes aegypti*	Yellow-fever mosquito	Larva	Exsanguination	$(0.3\text{-}0.4)^c$ cu mm/insect	17
2	*Apis mellifera*	Honeybee	Larva	Exsanguination	$(25\text{-}30)^c$ % body wt	4
3					0.04 g/insect	4
4	*Bombyx mori*	Silkworm	Larva	Exsanguination	$(0.15\text{-}0.22)^c$ ml/g body wt	3
5					0.35 ml/insect	8
6					$31.2(27.6\text{-}34.8)^b$ % body wt	15
7			Pupa	Exsanguination	$(0.11\text{-}0.31)^c$ ml/g body wt	3
8					$(0.09\text{-}0.35)^c$ ml/insect	8
9			Adult	Exsanguination	0.05 ml/insect	8
10	*Dytiscus* sp.	Diving beetle		Exsanguination	0.1 ml/insect	8
11	*Galleria mellonella*	Greater wax moth	Larva	Exsanguination	$41(36.6\text{-}45.4)^b$ % body wt (dry)	15
12	*Hyalophora cecropia*	Cecropia moth	Pupa	Exsanguination	0.25 ml/g body wt	6
13	*Locusta migratoria*	Migratory locust	Nymph	Exsanguination	<0.2 ml/insect	10
14			Adult	Exsanguination	$(0\text{-}1)^c$ cu mm/insect	10
	Periplaneta americana	American cockroach	Nymph			
15			Intermolt	Dye dilution	$17(11\text{-}30)^c$ % body wt	16
16			Molting	Dye dilution	$14(10\text{-}26)^c$ % body wt	16
17			♂	Dye dilution	$19.6(18.8\text{-}20.4)^b$ % body wt	18
18				Chloride	$20(16.3\text{-}23.7)^b$ % body wt[1]	18
19					$16.8(14.8\text{-}18.8)^b$ % body wt[2]	18
20				Cell dilution	$15.7(13.2\text{-}18.2)^b$ % body wt	18
21			♀	Dye dilution	$19.8(19.1\text{-}20.5)^b$ % body wt	18
22				Chloride	$18.6(14.5\text{-}22.7)^b$ % body wt[1]	18
23					$19.5(17.2\text{-}21.8)^b$ % body wt[2]	18
24				Cell dilution	$16.8(12.3\text{-}21.3)^b$ % body wt	18
			Adult			
25			Newly ecdysed	Dye dilution	$21(13\text{-}35)^c$ % body wt	16
26			24-hr old	Dye dilution	$15(13\text{-}19)^c$ % body wt	16
27			♂	Dye dilution	$27.5(23.8\text{-}31.2)^b$ % body wt	18
28				Chloride	$15.3(12.9\text{-}17.7)^b$ % body wt	18
29			♀	Dye dilution	$20.9(18.8\text{-}23.0)^b$ % body wt	18
30				Chloride	$16.9(11.9\text{-}21.9)^b$ % body wt	18
31	*Phormia regina*	Black blowfly	Larva		20 µl/insect	7
32			Adult	Dye dilution	$(6.6\text{-}10.2)^c$ µl/insect	9
33					20% body wt	9
34	*Popillia japonica*	Japanese beetle	Larva	Exsanguination	$(0.9\text{-}40.8)^c$% body wt	2
35				Manganese	$40.9(38.5\text{-}42.9)^c$ % body wt	2
36				Exsanguination	0.03 ml/insect	13

/1/ Individual. /2/ Pooled.

continued

85. BLOOD VOLUMES

Part II. INSECTS

	Species	Common Name	Stage	Method	Hemolymph Volume	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
37	*Prodenia eridania*	Southern armyworm	Larva	Exsanguination	0.12(0.07-0.20)[c] ml/insect	1
38				C^{14} inulin	0.19 ml/insect	12
39	*Tenebrio molitor*	Yellow mealworm	Larva	Dye dilution	10% body wt	11
40				Chloride	0.22 ml/g body wt	14

Contributors: (a) Jones, Jack Colvard, (b) Buck, John B.

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86. ERYTHROCYTE AND PLATELET VALUES

For information on additional species, consult reference 4, Part I.

Part I. ERYTHROCYTE AND HEMOGLOBIN VALUES: VERTEBRATES

Values in parentheses are ranges, estimate "c" unless otherwise indicated (cf. Introduction).

	Species (Common Name)	Erythrocyte Count million/cu mm blood	Erythrocyte Packed Volume (Hematocrit) ml/100 ml blood	Erythrocyte Volume (Mean Corpuscular) cu μ	Hemoglobin Concentration g/100 ml blood	Hemoglobin Concentration g/100 ml erythrocytes	Erythrocyte Hemoglobin Content μμg	Erythrocyte Dimensions[1] (Dry Film), μ	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
	Mammalia								
	Homo sapiens (man)								7-9, 12-14, 17, 23
1	At birth[2]	5.7 (4.8-7.1)	56.6	106	21.5 (18.0-27.0)	38.0	38		
2	1st da	5.6 (4.7-7.0)	56.1	106	21.2 (17.7-26.5)	37.8	38		
3	1st wk	5.3 (4.5-6.4)	52.7	101	19.6 (16.2-25.5)	37.2	37		
4	2nd wk	5.1 (4.3-6.0)	49.6	96	18.0 (14.5-24.2)	36.3	35		
5	3rd wk	4.9 (4.1-6.0)	46.6	93	16.6 (13.2-23.0)	35.6	34		
6	4th wk	4.7 (3.9-5.9)	44.6	91	15.6 (12.0-21.8)	35.0	33		

/1/ Dimensions for mammals are diameters. /2/ When cord was clamped after placental separation rather than immediately after birth, erythrocyte count was 560,000/cu mm greater, and hemoglobin 2.6 g/100 ml greater, during first week of life. Erythrocyte and hemoglobin values were higher for heel blood (capillary) than for blood from superior sagittal sinus.

continued

86. ERYTHROCYTE AND PLATELET VALUES

Part I. ERYTHROCYTE AND HEMOGLOBIN VALUES: VERTEBRATES

	Species (Common Name)	Erythrocyte Count million/cu mm blood	Erythrocyte Packed Volume (Hematocrit) ml/100 ml blood	Erythrocyte Volume (Mean Corpuscular) cu μ	Hemoglobin Concentration g/100 ml blood	Hemoglobin Concentration g/100 ml erythrocytes	Erythrocyte Hemoglobin Content μμg	Erythrocyte Dimensions[1] (Dry Film), μ	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
	Mammalia								
	Homo sapiens (man)								7-9, 12-14, 17, 23
7	2nd mo	4.5 (3.8-5.8)	38.9	85	13.3 (10.8-18.0)	34.2	30		
8	4th mo	4.5 (3.8-5.3)	36.5	79	12.4 (10.2-15.0)	34.0	27		
9	6th mo	4.6 (3.9-5.3)	36.2	78	12.3 (10.0-15.0)	34.0	27		
10	8th mo	4.6 (4.0-5.4)	35.8	77	12.1 (9.8-15.0)	33.8	26		
11	10th mo	4.6 (4.0-5.5)	35.5	77	11.9 (8.4-14.9)	33.5	26		
12	12th mo	4.6 (4.0-5.5)	35.2	77	11.6 (9.0-14.6)	33.0	25		
13	2nd yr	4.7 (3.8-5.4)	35.5	78	11.7 (9.2-15.5)	33.0	25		
14	4th yr	4.7 (3.8-5.4)	37.1	80	12.6 (9.6-15.5)	34.0	27		
15	6th yr	4.7 (3.8-5.4)	37.9	80	12.7 (10.0-15.5)	33.5	27		
16	8th yr	4.7 (3.8-5.4)	38.9	80	12.9 (10.3-15.5)	33.2	27		
17	10th yr	4.8 (3.8-5.4)	39.0	80	13.0 (10.7-15.5)	33.3	27		
18	12th yr	4.8 (3.8-5.4)	39.6	81	13.4 (11.0-16.5)	33.8	28		
	14 yr & over								6,19
19	Male	5.4 (4.6-6.2)[b]	47	(86-101)	15.8 (14.0-18.0)[b]	33.5	29	7.5 (7.2-7.8)[b]	
20	Female	4.8 (4.2-5.4)[b]	42	(86-101)	13.9 (11.5-16.0)[b]	33.5	29	7.5 (7.2-7.8)[b]	
	Pregnant								5
21	6 mo	4.0 (3.5-4.8)	37 (32-42)	92	11.4 (10.2-14.0)	31	28.5		
22	9 mo	4.2 (3.7-5.0)	37.5 (33-43)	89	12.0 (10.8-14.4)	32	28.5		
23	Postpartum, 10 da	4.5 (4.0-5.0)	40 (35-45)	89	12.8 (11.4-14.4)	32	28.4		5
24	*Bos taurus* (cattle)	8.1 (6.1-10.7)	40 (33-47)[b]	50 (47-54)	11.5 (8.7-14.5)[b]	29.0		5.9	1
25	*Canis familiaris* (dog)	6.3 (4.5-8.0)	45.5 (38-53)	66 (59-68)	14.8 (11.0-18.0)	33 (30-35)	23 (21-25)	7.0 (6.2-8.0)	1
26	*Capra hircus* (goat)	16.0 (13.3-17.9)	33 (27.0-34.6)	19.3	10.5 (8.8-11.4)	34 (33-36)	6.7	4.0	22
27	*Cavia porcellus* (guinea pig)	5.6 (4.5-7.0)	42 (37-47)	77 (71-83)	14.4 (11.0-16.5)	34 (33-35)	26.0 (24.5-27.5)	7.4 (7.0-7.5)	1
28	*Equus caballus* (horse)	9.3 (8.21-10.35)[b]	33.4 (28-42)[b]		11.1 (8-14)[b]	33.0		5.5	1
29	*Felis catus* (cat)	8.0 (6.5-9.5)	40 (28-52)	57 (51-63)	11.2 (7.0-15.5)	28 (23-31)	14 (12-16)	6.0 (5.0-7.0)	1
30	*Macaca mulatta* (rhesus monkey)	5.2 (3.6-6.8)[b]	42 (32-52)[b]		12.6 (10-16)[b]	30.0			1
31	*Mesocricetus auratus* (golden hamster)	6.96 (3.96-9.96)[b]	49 (39-59)[b]	70.0	16.0 (2.0-30.0)[b]	32.0	23.0	5.6 (5.4-5.8)[b]	11
32	*Mus musculus* (house mouse)	9.3 (7.7-12.5)	41.5	49 (48-51)	14.8 (10-19)	36 (33-39)	16 (15.5-16.5)	6.0	1

/1/ Dimensions for mammals are diameters.

continued

86. ERYTHROCYTE AND PLATELET VALUES

Part I. ERYTHROCYTE AND HEMOGLOBIN VALUES: VERTEBRATES

	Species (Common Name)	Erythrocyte Count million/cu mm blood	Erythrocyte Packed Volume (Hematocrit) ml/100 ml blood	Erythrocyte Volume (Mean Corpuscular) cu µ	Hemoglobin Concentration		Erythrocyte Hemoglobin Content µµg	Erythrocyte Dimensions[1] (Dry Film), µ	Reference
					g/100 ml blood	g/100 ml erythrocytes			
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
	Mammalia								
33	*Oryctolagus cuniculus* (European rabbit)	5.7 (4.5-7.0)	41.5 (33-50)	61 (60-68)	11.9 (8.0-15.0)	29 (27-31)	21 (19-23)	7.5 (6.5-7.5)	1
34	*Ovis aries* (sheep)	10.3 (9.4-11.1)	31.7 (29.9-33.6)	31 (30-32)	10.9 (10.0-11.8)	34.5 (34-35)	11.0	4.8	22
35	*Rattus norvegicus* (Norway rat)	8.9 (7.2-9.6)	46 (39-53)	55 (52-58)	14.8 (12.0-17.5)	32 (30-35)	17 (15-19)	7.5 (6.0-7.5)	1,18
36	*Sus scrofa* (swine)	6.4	39.0 (38.0-40.0)	61.1 (59-63)	13.7 (13.2-14.2)	35.0	21.5 (21-22		22
	Aves								
37	*Anas platyrhynchos* (duck)[3]	2.8	39.5		14.8 (9-21)	38.1	52.1 (32-71)	12.8 x 6.6	21
38	*Anser domesticus* (common goose)	2.8 (2.6-3.0)	44.7 (43.1-46.2)	160 (145-174)	12.7 (11.9-13.4)	28.5 (28-29)	45.5 (40-51)	12.2 x 7.2	22
39	*Columba livia* (street pigeon)	3.2	42.3	131.0	12.8	30.0	40.0	13.2 x 6.9	22
40	*Gallus domesticus* (chicken)	2.8 (2.0-3.2)	35.6 (24.0-43.3)	127 (120-137)	10.3 (7.3-12.9)	29 (27-30)	36.6 (33-41)	11.2 x 6.8	22
41	*Meleagris gallopavo* (turkey)	2.3	38.0		11.2	23.5		15.5 x 7.5	21
	Reptilia								
42	*Alligator mississipiensis* (American alligator)	0.67	30.0	450.0	8.2	27.0	123.0	23.2 x 12.1	22
43	*Natrix sipedon* (North American water snake)	0.77	35.5	465.0	10.0	28.0	131.0	19.6 x 11.0	22
44	*Pseudemys scripta elegans* (red-eared turtle)	0.69 (0.53-0.78)	17.5 (15-21)	255 (211-296)	7.3 (5.9-8.9)	41.7 (39.3-42.3)	106 (96-118)		15
45	*Terrapene carolina* (box turtle)	0.65 (0.41-0.83)	28.6 (20-38)	442 (309-587)	5.9 (5.0-8.5)	20.6 (17.4-29.7)	91 (79-131)	19 x 9	2,3
46	*Thamnophis sirtalis* (common garter snake)	1.05 (0.71-1.39)	28 (19-37)	267 (266-268)	8.5 (5.8-11.3)	31.0	82.0	18.1 x 10.3	22
	Amphibia								
47	*Ambystoma tigrinum* (tiger salamander)	1.68 (1.13-1.94)	42 (27-48)	250	8.6 (5.6-10.9)	20.4	51.1		20
48	*Amphiuma means* (two-toed amphiuma)	0.03	40 (39-41)	13,857 (13,200-14,513)	9.4 (7.17-11.0)	24 (21-27)	3,287 (2,750-3,823)	62.5 x 36.3	22
49	*Cryptobranchus alleganiensis* (hellbender)	0.07	49.0	7,425	13.3	27.0	2,010	40.5 x 21.0	22
50	*Necturus maculosus* (mud puppy)	0.02	21.4	10,070	4.6	22.0	2,160	52.8 x 28.2	22

/1/ Dimensions for mammals are diameters; dimensions for other vertebrates are length x width. /3/ As ducks mature, hematological values progressively increase.

continued

86. ERYTHROCYTE AND PLATELET VALUES

Part I. ERYTHROCYTE AND HEMOGLOBIN VALUES: VERTEBRATES

	Species (Common Name)	Erythrocyte Count million/cu mm blood	Erythrocyte Packed Volume (Hematocrit) ml/100 ml blood	Erythrocyte Volume (Mean Corpuscular) cu μ	Hemoglobin Concentration g/100 ml blood	Hemoglobin Concentration g/100 ml erythrocytes	Erythrocyte Hemoglobin Content μμg	Erythrocyte Dimensions[1] (Dry Films), μ	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
	Amphibia								
51	***Rana catesbeiana*** **(American bullfrog)**	0.44 (0.43-0.45)	29.3 (26.6-32.0)	670 (625-716)	7.8 (7.4-8.2)	27 (26-28)	179 (174-184)	24.8 x 15.3	22
	Pisces								
52	***Anguilla rostrata*** **(American freshwater eel)**	2.48	37.9 (36.0-39.8)	156 (141-170)	9.0 (8.0-10.0)	23.5 (22-25)	36.5 (35-38)	13.0 x 8.0	22
53	***Cyprinus carpio*** **(carp)**	0.84 (0.65-1.13)	31.3 (21-40)	311 (278-340)	10.5 (9.4-12.4)	33.5	72 (63-78)		10
54	***Gadus callarias*** **(rock cod)**	1.55 (1.49-1.60)	29.1 (23.8-32.6)	186 (159-201)	5.9 (5.2-6.4)	20 (19-22)	38 (35-40)	12.2 x 9.0	22
55	***Ictalurus catus*** **(white catfish)**	2.65	15.4	123	9.2	28	35	10.4 x 8.7	22
56	***Limanda ferruginea*** **(yellowtail flounder)**	1.23 (0.78-1.61)	14.6 (8.4-18.2)	117.7 (107-138)	3.2 (2.1-4.2)	22.7 (19-25)	26.7 (26-28)	10.3 x 7.7	22
57	***Salvelinus fontinalis*** **(eastern brook trout)**	1.01 (0.74-1.50)	27.2 (22-36)	314 (284-348)	8.5 (6.2-11.5)	31.2	75 (61-82)		10
58	***Scomber scombrus*** **(Atlantic mackerel)**	3.94 (3.68-4.20)	57.5 (56-59)	146 (140-152)	14.9 (14.5-15.2)	26.0	37.5 (36-39)	12.5 x 8.3	22
	Chondrichthyes and Agnatha								
59	***Dasyatis centroura*** **(roughtail stingray)**	0.30	19.0	612	3.0			20.6 x 14.3	16
60	***Myxine glutinosa*** **(Atlantic hagfish)**	0.15 (0.12-0.19)	22.2 (19.3-27.6)	1,530 (1,470-1,560)	4.6 (4.0-5.7)	21.0	318.3 (303-330)	26.4 x 18.3	22
61	***Petromyzon marinus*** **(sea lamprey)**	0.33	23.5	710.0	5.8			14.3 x 14.3	16
62	***Raja erinacea*** **(little skate)**	0.09 (0.07-0.11)	7.2 (4.7-9.6)	778 (646-910)	1.4 (0.9-1.8)	19.5 (19-20)	148.5 (125-172)	24.3 x 13.9	22
63	***Sphyrna zygaena*** **(hammerhead shark)**	0.44	23.1	526	5.4			15.2 x 11.2	16
64	***Squalus acanthias*** **(Atlantic spiny dogfish)**	0.24	18.9	820.0	3.8			22.7 x 15.2	16

/1/ Dimensions for vertebrates other than mammals are length x width.

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continued

86. ERYTHROCYTE AND PLATELET VALUES

Part I. ERYTHROCYTE AND HEMOGLOBIN VALUES: VERTEBRATES

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Part II. BLOOD PLATELET COUNT: MAMMALS

Values in parentheses are ranges, estimate "c" unless otherwise indicated (cf. Introduction).

	Species (Common Name)	Platelets thousands/cu mm	Remarks	Reference
	(A)	(B)	(C)	(D)
	Homo sapiens (man)			
	Infant		Direct method of Wood, Vogel, and Famulener; cutaneous blood	7,19
1	At birth	227(140-290)	73 observations	
2	1 wk	233(160-320)	69 observations	
3	2 wk	242(170-370)	19 observations	
4	3 wk	269(160-380)	23 observations	
5	1 mo	277(200-370)	48 observations	
6	2 mo	320(200-470)	59 observations	
7	4 mo	324(180-450)	56 observations	
8	6 mo	350(200-480)	47 observations	
9	8 mo	346(220-480)	28 observations	
10	10 mo	340(200-450)	23 observations	
11	1 yr	339(250-470)	15 observations	
12	Adult	250(140-440)	13♂; direct method, phase microscopy; venous blood	1
13		260(145-375)	♂♀, 185 observations; direct method, phase microscopy; venous and capillary blood	8
14	*Bos taurus* (cattle)	350(250-600)	.....	11
15		(550-600)	.....	2
16	*Canis familiaris* (dog)	326	Direct method, phase microscopy	15
17		300(100-600)	.....	11
18	*Capra hircus* (goat)	350(250-600)	.....	11
19	*Cavia porcellus*	783(525-900)	4 subjects, 8 determinations; direct method; blood from ear	16
20	(guinea pig)	773(680-865)	.....	18
21	*Equus caballus* (horse)	250(100-500)	.....	11
22	*Felis catus* (cat)	250(100-500)	.....	11
23	*Macaca mulatta*	344(250-750)	57 subjects	6
24	(rhesus monkey)	414	Direct method, no phase microscopy	12
25	*Mesocricetus auratus*	688(504-880)	10♂; direct method	10
26	(golden hamster)	742(500-870)	12♀; direct method	10
27	*Mus musculus* (house	1,520	92♂; direct method, phase microscopy	9
28	mouse)	1,190	22♂; direct method, no phase microscopy	14
29	*Oryctolagus cuniculus*	400	24 subjects; direct method, phase microscopy	3
30	(European rabbit)	(380-520)	12 subjects	13
31	*Rattus norvegicus*	1,240(1,100-1,380)[b]	60 subjects; direct method, phase microscopy	4
32	(Norway rat)	1,190(1,000-1,300)	18 subjects	5
33	*Sus scrofa* (swine)	445(383-507)	.....	17
34		350(250-600)	.....	11

continued

86. ERYTHROCYTE AND PLATELET VALUES

Part II. BLOOD PLATELET COUNT: MAMMALS

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87. LEUKOCYTE COUNTS

For additional information, consult reference 1, Part 1.

Part I. MAN

Values were derived from smoothed curves plotted from data given in the references. Unless designated as percent (of total leukocytes), values are thousands/cu mm blood. Values in parentheses are ranges, estimate "c" (cf. Introduction).

	Age	Leukocytes, Total[1]	Neutrophils			Eosinophils	Basophils	Lymphocytes	Monocytes
			Total	Band[2]	Segmented				
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
1	At birth	18.1(9.0-30.0)[3]	11.0(6.0-26.0) 61%	1.65 9.1%	9.4 52%	0.40(0.02-0.85) 2.2%	0.10(0-0.64) 0.6%	5.5(2.0-11.0) 31%	1.05(0.40-3.1) 5.8%
2	12 hr	22.8(13.0-38.0)	15.5(6.0-28.0) 68%	2.33 10.2%	13.2 58%	0.45(0.02-0.95) 2.0%	0.10(0-0.50) 0.4%	5.5(2.0-11.0) 24%	1.20(0.40-3.6) 5.3%
3	24 hr	18.9(9.4-34.0)	11.5(5.0-21.0) 61%	1.75 9.2%	9.8 52%	0.45(0.05-1.00) 2.4%	0.10(0-0.30) 0.5%	5.8(2.0-11.5) 31%	1.10(0.20-3.1) 5.8%
4	1 wk	12.2(5.0-21.0)	5.5(1.5-10.0) 45%	0.83 6.8%	4.7 39%	0.50(0.07-1.10) 4.1%	0.05(0-0.25) 0.4%	5.0(2.0-17.0) 41%	1.10(0.30-2.7) 9.1%
5	2 wk	11.4(5.0-20.0)	4.5(1.0-9.5) 40%	0.63 5.5%	3.9 34%	0.35(0.07-1.00) 3.1%	0.05(0-0.23) 0.4%	5.5(2.0-17.0) 48%	1.00(0.20-2.4) 8.8%
6	4 wk	10.8(5.0-19.5)	3.8(1.0-9.0) 35%	0.49 4.5%	3.3 30%	0.30(0.07-0.90) 2.8%	0.05(0-0.20) 0.5%	6.0(2.5-16.5) 56%	0.70(0.15-2.0) 6.5%
7	2 mo	11.0(5.5-18.0)	3.8(1.0-9.0) 34%	0.49 4.4%	3.3 30%	0.30(0.07-0.85) 2.7%	0.05(0-0.20) 0.5%	6.3(3.0-16.0) 57%	0.65(0.13-1.8) 5.9%
8	4 mo	11.5(6.0-17.5)	3.8(1.0-9.0) 33%	0.45 3.9%	3.3 29%	0.30(0.07-0.80) 2.6%	0.05(0-0.20) 0.4%	6.8(3.5-14.5) 59%	0.60(0.10-1.5) 5.2%
9	6 mo	12.0(6.0-17.5)	3.8(1.0-8.5) 32%	0.45 3.8%	3.3 28%	0.30(0.07-0.75) 2.5%	0.05(0-0.20) 0.4%	7.3(4.0-13.5) 61%	0.58(0.10-1.3) 4.8%
10	8 mo	12.2(6.0-17.5)	3.7(1.0-8.5) 30%	0.41 3.3%	3.3 27%	0.30(0.07-0.70) 2.5%	0.05(0-0.20) 0.4%	7.6(4.5-12.5) 62%	0.58(0.08-1.2) 4.7%
11	10 mo	12.0(6.0-17.5)	3.6(1.0-8.5) 30%	0.40 3.3%	3.2 27%	0.30(0.06-0.70) 2.5%	0.05(0-0.20) 0.4%	7.5(4.5-11.5) 63%	0.55(0.05-1.2) 4.6%
12	12 mo	11.4(6.0-17.5)	3.5(1.5-8.5) 31%	0.35 3.1%	3.2 28%	0.30(0.05-0.70) 2.6%	0.05(0-0.20) 0.4%	7.0(4.0-10.5) 61%	0.55(0.05-1.1) 4.8%
13	2 yr	10.6(6.0-17.0)	3.5(1.5-8.5) 33%	0.32 3.0%	3.2 30%	0.28(0.04-0.65) 2.6%	0.05(0-0.20) 0.5%	6.3(3.0-9.5) 59%	0.53(0.05-1.0) 5.0%

/1/ Mean value is sum of means in columns C, F-I. /2/ Includes a small percentage of myelocytes during first few days after birth. /3/ Approximately 3 nucleated erythrocytes per 100 leukocytes have been found at birth.

continued

87. LEUKOCYTE COUNTS

Part I. MAN

	Age	Leukocytes, Total[1]	Neutrophils Total	Neutrophils Band[2]	Neutrophils Segmented	Eosinophils	Basophils	Lymphocytes	Monocytes
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
14	4 yr	9.1(5.5-15.5)	3.8(1.5-8.5) 42%	0.27 3.0%	3.5 39%	0.25(0.02-0.65) 2.8%	0.05(0-0.20) 0.6%	4.5(2.0-8.0) 50%	0.45(0-0.8) 5.0%
15	6 yr	8.5(5.0-14.5)	4.3(1.5-8.0) 51%	0.25 3.0%	4.0 48%	0.23(0-0.65) 2.7%	0.05(0-0.20) 0.6%	3.5(1.5-7.0) 42%	0.40(0-0.8) 4.7%
16	8 yr	8.3(4.5-13.5)	4.4(1.5-8.0) 53%	0.25 3.0%	4.1 50%	0.20(0-0.60) 2.4%	0.05(0-0.20) 0.6%	3.3(1.5-6.8) 39%	0.35(0-0.8) 4.2%
17	10 yr	8.1(4.5-13.5)	4.4(1.8-8.0) 54%	0.24 3.0%	4.2 51%	0.20(0-0.60) 2.4%	0.04(0-0.20) 0.5%	3.1(1.5-6.5) 38%	0.35(0-0.8) 4.3%
18	12 yr	8.0(4.5-13.5)	4.4(1.8-8.0) 55%	0.24 3.0%	4.2 52%	0.20(0-0.55) 2.5%	0.04(0-0.20) 0.5%	3.0(1.2-6.0) 38%	0.35(0-0.8) 4.4%
19	14 yr	7.9(4.5-13.0)	4.4(1.8-8.0) 56%	0.24 3.0%	4.2 53%	0.20(0-0.50) 2.5%	0.04(0-0.20) 0.5%	2.9(1.2-5.8) 37%	0.38(0-0.8) 4.7%
20	16 yr	7.8(4.5-13.0)	4.4(1.8-8.0) 57%	0.23 3.0%	4.2 54%	0.20(0-0.50) 2.6%	0.04(0-0.20) 0.5%	2.8(1.2-5.2) 35%	0.40(0-0.8) 5.1%
21	18 yr	7.7(4.5-12.5)	4.4(1.8-7.7) 57%	0.23 3.0%	4.2 54%	0.20(0-0.45) 2.6%	0.04(0-0.20) 0.5%	2.7(1.0-5.0) 35%	0.40(0-0.8) 5.2%
22	20 yr	7.5(4.5-11.5)	4.4(1.8-7.7) 59%	0.23 3.0%	4.2 56%	0.20(0-0.45) 2.7%	0.04(0-0.20) 0.5%	2.5(1.0-4.8) 33%	0.38(0-0.8) 5.0%
23	21 yr	7.4(4.5-11.0)	4.4(1.8-7.7) 59%	0.22 3.0%	4.2 56%	0.20(0-0.45) 2.7%	0.04(0-0.20) 0.5%	2.5(1.0-4.8) 34%	0.30(0-0.8) 4.0%

/1/ Mean value is sum of means in columns C, F-I. /2/ Includes a small percentage of myelocytes during first few days after birth.

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Part II. VERTEBRATES OTHER THAN MAN

Unless designated as percent (of total leukocytes), values are thousands/cu mm blood. Values in parentheses are ranges, estimate "c" (cf. Introduction).

	Species (Common Name)	Leukocytes, Total	Neutrophils	Eosinophils	Basophils	Lymphocytes	Monocytes	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Mammalia							
1	*Bos taurus* (cattle)	9.2 (6.0-12.0)	2.9(1.9-3.7) 31.9(20-40)%	0.7(0.3-1.3) 7.7(3-15)%	0.06(0-0.09) 0.62(0-1)%	5.09(4.1-5.9) 55.4(45-65)%	0.48(0.27-1.40) 5.2(3-15)%	8

continued

87. LEUKOCYTE COUNTS

Part II. VERTEBRATES OTHER THAN MAN

	Species (Common Name)	Leuko-cytes, Total	Neutrophils	Eosinophils	Basophils	Lymphocytes	Monocytes	Ref-er-ence
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Mammalia							
2	*Canis familiaris* (dog)	12.0 (8.0-18.0)	8.2(6.0-12.5) 68(62-80)%	0.6(0.2-2.0) 5.1(2-14)%	0.085(0-0.3) 0.7(0-2)%	2.5(0.9-4.5) 21(10-28)%	0.65(0.3-1.5) 5.2(3-9)%	1
3	*Capra hircus* (goat)	(5.0-14.0)	(2.10-3.35)	(0-1.1)	(0-0.6)	(2.10-11.25)	(0.05-0.60)	4
4	*Cavia* sp. (guinea pig)	10.0 (7.0-19.0)	4.2(2.0-7.0) 42(22-50)%	0.4(0.2-1.3) 4(2-12)%	0.07(0-0.3) 0.7(0-2)%	4.9(3.0-9.0) 49(37-64)%	0.43(0.25-2.00) 4.3(3-13)%	1
5	*Equus caballus* (horse)	(5.0-11.0)	(3.0-6.9)	(0.05-0.60)	(0-0.1)	(1.2-4.8)	(0.10-1.45)	4
6	*Felis catus* (cat)	16.0 (9.0-24.0)	9.5(5.5-16.5) 59.5(44-82)%	0.85(0.2-2.5) 5.4(2-11)%	0.02(0-0.1) 0.1(0-0.5)%	5.0(2.0-9.0) 31(15-44)%	0.65(0.05-1.40) 4(0.5-7.0)%	1
7	*Mus* sp. (mouse)	8.0 (4.0-12.0)	2.0(0.7-4.0) 25.5(12-44)%	0.15(0-0.5) 2(0-5)%	0.05(0-0.1) 0.5(0-1)%	5.5(3.0-8.5) 68(54-85)%	0.3(0-1.3) 4(0-15)%	1
8	*Oryctolagus cuniculus* (rabbit)	9.0 (6.0-13.0)	4.1(2.5-6.0) 46(36-52)%	0.18(0-0.4) 2(0.5-3.5)%	0.45(0.15-0.75) 5(2-7)%	3.5(2.0-5.6) 39(30-52)%	0.725(0.3-1.3) 8(4-12)%	1
9	*Ovis aries* (sheep)	7.8(5-10)	2.8(1.6-3.5) 35.7(20-45)%	0.19(0.08-0.5) 2.5(1-7)%	0.3(0-0.15) 0.4(0-2)%	4.4(3.9-5.5) 56.9(50-70)%	0.47(0.08-0.60) 6(1-8)%	8
10	*Rattus* sp. (rat)	14.0 (5.0-25.0)	3.1(1.1-6.0) 22(9-34)%	0.3(0-0.7) 2.2(0-6)%	0.1(0-0.2) 0.5(0-1.5)%	10.2(7.0-16.0) 73(65-84)%	0.3(0-0.65) 2.3(0-5)%	1
11	*Sus scrofa* (swine)	(7.0-20.0)	(2.4-10.0)	(0.05-2.00)	(0-0.8)	(3.2-12.0)	(0.05-2.00)	4
	Aves							
12	*Anas* sp. (duck)	23.4	24.3%	2.1%	1.0(0-4.5)	45.8(13.0-73.5)	4.4(0.5-11.5)	6,9
13	*Gallus domesticus* (chicken)	32.6 (9.1-56.0)	9.1(3.0-18.2)[1] 27.8(9.1-56.0)%	0.05(0-0.23)[2] 1.5(0-7)%	0.9(0-2.6) 2.7(0-8)%	17.6(7.8-27.3) 54(24-84)%	4.4(0-9.7) 13.7(0-30)%	10
14	*Meleagris gallopavo*	19.0	44.5(35-65)[3,4]	7.5(1-24)[3,5]	6.9(3-11)[3]	36.3(22-46)[3]	7.3(2-11)[3]	5
15	(turkey)	(16.0-25.5)	45.4(39-52)[4,6]	2.3(0-5)[5,6]	5.1(1-9)[6]	40.9(35-48)[6]	6.5(3-10)[6]	
	Reptilia							
16	*Pituophis sayi* (bull snake)	50.2[7]	2.7[1,2] 5.4%		0.01 0.2%	19.7 39.4%	3.4 6.9%	7
17	*Terrapene carolina* (box turtle)	37.5 (24.0-48.0)	0.01[7] 0.3%	4.1 10.8%	3.0 8%	21.0 56.1%	3.5 9.4%	2,3

/1/ Heterophils with rod-shaped eosinophilic bodies. /2/ Heterophils with granular eosinophilic bodies. /3/ Supravital stain. /4/ Polymorphic myelocytes with eosinophilic rods. /5/ Polymorphic myelocytes with pseudoeosinophilic granules. /6/ Wright's stain. /7/ Includes thrombocytes.

Contributors: (a) Altland, Paul D., (b) Dunlap, J. S., (c) Rigdon, R. H.

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88. BONE MARROW DIFFERENTIAL CELL COUNTS

Part I. RIB: DOG

Values in parentheses are ranges, estimate "c" unless otherwise specified (cf. Introduction).

	Specification	Values from Mulligan	Mulligan	Rekers and Coulter	Stasney and Higgins[1]	Van Loon and Clark
	(A)	(B)	(C)	(D)	(E)	(F)
1	Number of subjects	21	35	36	35	81
2	Age of subjects	0.5-2.5 da	Adult	19-24 mo	Adult	Adult
	Cells, % of total count					
3	Proerythroblasts	1.3(0.4-3.2)[2]	0.5(0-1.4)[2]	0.3(0-1.3)[3]		0.6(0.2-2.7)[2]
	Normoblasts					
4	Early	5.8(3.0-9.5)[4]	1.5(0.4-3.8)[5]	28.2(8.0-53.9)[4]	59(40-78)	7.8(6.4-10.0)[5]
5	Intermediate	45.1(33.0-56.6)[6]	38.1(18.6-63.6)[6]			16.4(11-26)[7]
6	Late			4.6(0-11.2)[8]		17.4(9-26)[8]
7	Myeloblasts		0.6(0-1.8)	1.9(0.2-3.7)	2.4(0-5.1)[9]	0.6(0.2-1.0)
8	Promyelocytes	0.8(0-2.2)	1.5(0.2-4.6)	0.7(0-3.3)	2.8(0-5.8)	1.6(0.7-2.8)
9	Myelocytes			2.7(0-9.5)		6.0(2.7-10.0)
10	Neutrophilic	4.3(2.0-6.6)	4.7(2.2-11.2)		8.9(2.8-15.0)	
11	Eosinophilic				1.2(0-2.4)	
12	Metamyelocytes	9.7(7.2-12.0)	10.5(5.6-20.0)	5.1(0-24.4)[10]	15.3(7.2-23.0)	3.4(1.1-4.6)
13	Band cells	20.6(14.8-28.4)[11]	31.0(16.8-53.8)[11]	42.4(16.5-62.9)[11]		11.7(6.8-17.0)
	Segmented cells					
14	Neutrophilic	3.4(0.8-6.6)	3.9(0.2-8.6)	5.0(0.2-14.3)	5.1(0-12.5)	30.1(17-44)
15	Eosinophilic	2.4(0-5.2)	3.7(1.0-6.8)	4.7(0.2-19.3)	2.8(0-6.8)	2.0(0.4-3.8)
16	Basophilic			0.2(0-1.3)	0.1(0-0.3)	
17	Lymphocytes	3.3(1.6-6.0)	1.9(0-6.6)	0.7(0-8)	1.2(0.2-2.3)	0.9(0.2-2.7)
18	Monocytes					0.2(0-0.3)
19	Megakaryocytes			0.6(0-1.1)	0.1(0-0.5)	0.5(0-1.4)
20	Plasma cells			0.4(0-2.1)		
21	Reticulum cells				1.0(0-2.1)	
22	Unclassified cells	3.1(0.8-5.4)	2.1(0.8-6.1)	3.0(0-15.7)	0.2(0-0.7)[12]	
	Reference	1	2	3	4	5

/1/ Ranges are estimate "b" (cf. Introduction). /2/ Pronormoblasts. /3/ Megaloblasts /4/ Erythrocytes. /5/ Basophilic normoblasts. /6/ Normoblasts. /7/ Polychromic normoblasts. /8/ Ortnochromic normoblasts. /9/ Includes leukoblasts. /10/ Juvenile cells. /11/ Stab cells. /12/ Includes heterophils.

Contributor: Rekers, Paul E.

References: [1] Mulligan, R. M. 1941. Anat. Record 79:101. [2] Mulligan, R. M. 1945. Ibid. 91:161. [3] Rekers, P. E., and M. Coulter. 1948. Am. J. Med. Sci. 216:643. [4] Stasney, J., and G. M. Higgins. 1937. Ibid. 193:462. [5] Van Loon, E. J., and B. B. Clark. 1943. Clin. Med. 28:1575.

Part II. STERNUM: MAN

For additional information, consult reference 1. All values are for adults. Values in parentheses are ranges, estimate "c" unless otherwise specified (cf. Introduction).

	Specification	Values from Berman	Diggs	Israëls	Leitner	Lucia and Hunt[1]	Osgood and Seaman[1,2]	Vaughan and Brockmyre	Whitby and Britton	Wintrobe
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
1	Number of subjects	19♂♀			20♂♀	6♂♀	28♂, 24♀	42♂, 8♀		
2	Marrow aspirated, ml	1.5	(0.1-0.2)	0.2	(0.1-0.3)	0.5	(0.5-10.0)	3.0	0.25	(1.0-2.0)
3	Nucleated cells, total, thousands/cu mm				(60-100)		35 (10-100)	35.3 (9.4-74.0)		

/1/ Ranges are estimate "b" (cf. Introduction). /2/ Values are smoothed weighted means and calculated ranges.

continued

88. BONE MARROW DIFFERENTIAL CELL COUNTS

Part II. STERNUM: MAN

	Specification	Berman	Diggs	Israëls	Leitner	Lucia and Hunt[1]	Osgood and Seaman[1,2]	Vaughan and Brockmyre	Whitby and Britton	Wintrobe
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Cells, % of total count									
4	Proerythroblasts	3[3,4]	(0-1)[5]	(0.5-4.0)	0.8[6]	0.6(0-3.4)[7]	0.2(0-1)[8]		(0-4)	4(1-8)[4]
5	Normoblasts							9.5 (1.5-24.0)[9]		18(7-32)
6	Early	10[3,10]	(1-4)[11]	(1-5)	3.2[6,12]	8(0-20.4)[13]	2.0(0-4)[14]		(4-15)	
7	Intermediate	86[3,15]	(10-20)[16]	(12-20)	24.4[6,9]		6.0(4-8)[17]			
8	Late	1[3,18]	(5-10)[19]	(6-10)		12(0-25)[9]	3.0(1-5)[20]		(7-19)	
9	Myeloblasts	3[21]	(0-1)	(0.3-2.0)	1.2	1.0(0-2.8)	0.4(0-1)[22]	1.3(0-3)	(0-2.5)	2(0.3-5)
10	Promyelocytes	9	(1-5)	(1-8)	2.2	4(1.2-6.8)	1.4(0-3)		(0.5-5.0)	5(1-8)
11	Myelocytes							8.9(2-16)		
12	Neutrophilic	6	(2-10)	(5-20)	12.6[23]	10.2 (4.0-16.4)	4.2(0-12)[23]		(2-8)	12(5-19)
13	Eosinophilic				1.4	0.8(0-1.8)			(0-1)	1.5(0.5-3)
14	Basophilic				0.02					0.3(0-0.5)
15	Metamyelocytes						6.5(3-10)[24]	8.8 (3.5-18.0)[25]		22(13-32)
16	Neutrophilic	9	(5-15)	(13-32)[26]	10.2	13.2 (7.8-18.6)			(10-25)	
17	Eosinophilic				0.8	1.3(0.5-2.1)			(0-2.5)	
18	Band cells						24(17-33)[27]	23.9(12-34)		
19	Neutrophilic	31	(10-40)		24	24.6(5.2-44)				
	Segmented cells									
20	Neutrophilic	17	(10-30)	(7-30)	28.4	10(0-22.4)[28]	15(5-25)[29]	18.5(6-36)[30]	(10-40)[28,28]	20(7-30)[28]
21	Eosinophilic	2	(0-3)	(0.5-4.0)	1.8	0.3(0-0.9)[28]	2(0-4)[29]	1.9(0-6.5)[30]	(0-4)[28,28]	2(0.5-4)[28]
22	Basophilic		(0-1)	(0-1)	0.02		0.2 (0-0.5)[29]	0.2(0-1.5)[30]	(0-1)[28]	0.2(0-0.7)[28]
23	Lymphocytes	14	(5-15)	(3-20)	7.6	10.3 (1.5-19.1)	14(3-25)	16.2(7-35)	(5-20)	10(3-17)
24	Monocytes		(0-2)	(0.5-5.0)	1.4	0.5	2(0-4)	2.4(0-6)	(0-5)	2(0.5-5)
25	Megakaryocytes	5		±[31]	0.8					0.4(0.03-3)
26	Plasma cells	1	(0-1)	(0-2)	1.2	1.5(0-4.1)		0.3(0-1.5)	(0-1)	0.4(0-2)
27	Reticulum cells	2		±[31]	0.4[32]			0.3(0-2.5)[33]		0.2(0.1-2)
28	Unclassified cells				3.5			0.02(0-0.5)		
29	Disintegrated cells						19(10-30)	7.9(0-18)		
	Reference	2	3	4	5	6	7	8	9	10

/1/ Ranges are estimate "b" (cf. Introduction). /2/ Values are smoothed weighted means and calculated ranges. /3/ Percent of red series. /4/ Pronormoblasts. /5/ Rubriblasts. /6/ Per 100 leukocytes. /7/ Megaloblasts. /8/ Karyoblasts. /9/ Normoblasts. /10/ Basophilic normoblasts. /11/ Prorubricytes. /12/ Macroblasts. /13/ Erythroblasts. /14/ Prokaryocytes. /15/ Polychromatophilic normoblasts. /16/ Rubricytes. /17/ Karyocytes. /18/ Orthochromic normoblasts. /19/ Metarubricytes. /20/ Metakaryocytes. /21/ Includes leukoblasts. /22/ Granuloblasts. /23/ Includes early neutrophilic myelocytes. /24/ Metagranulocytes. /25/ Young forms. /26/ Includes band cells. /27/ Rhabdocytes. /28/ Polymorphonuclear cells. /29/ Lobocytes. /30/ Filament cells. /31/ Occasionally present. /32/ Endothelial cells. /33/ Reticuloendothelial cells.

Contributors: (a) Diggs, L. W., (b) Osgood, Edwin E.

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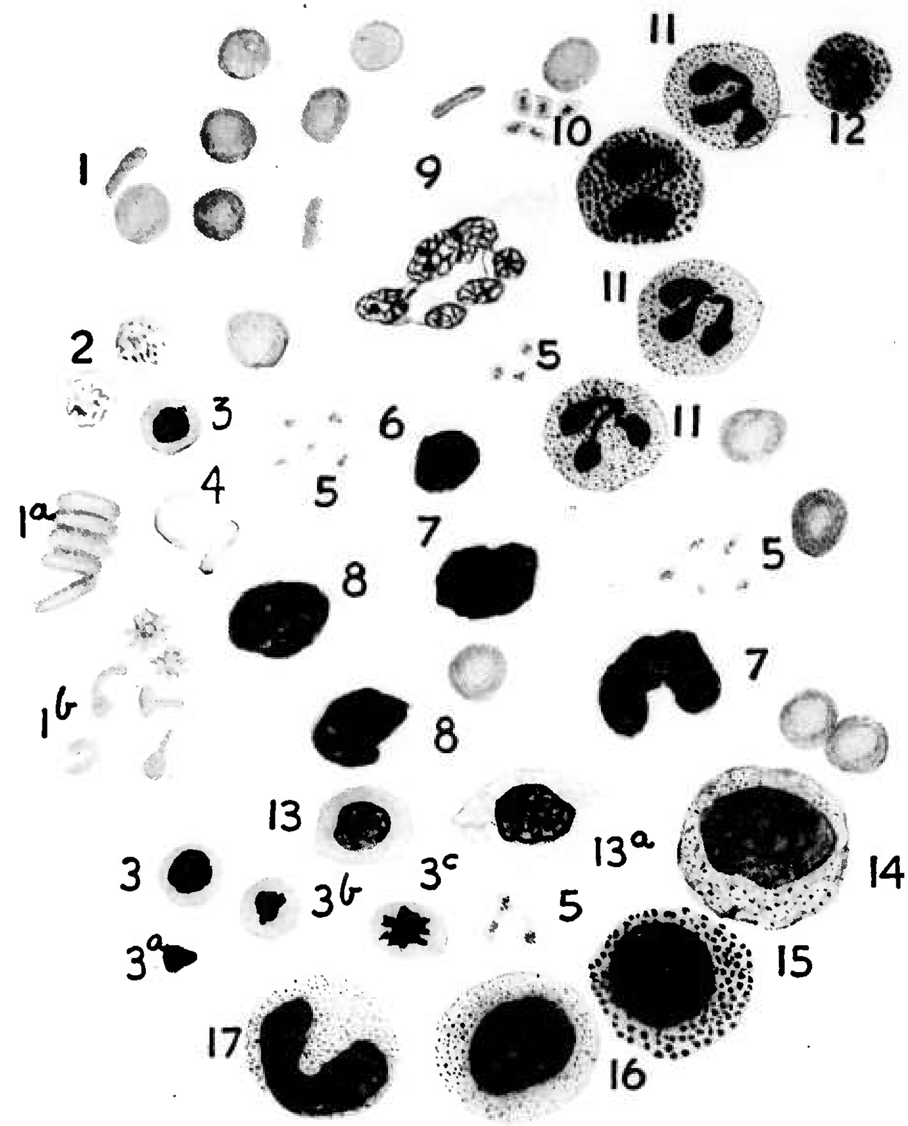
NORMAL BLOOD AND MARROW CELLS: MAN



1 Erythrocytes
1a Erythrocytes in rouleau
1b Deformed cells (poikilocytes), crenated forms
2 Reticulocytes stained with dilute solution of cresyl blue
3 Early normoblasts
3a Extruded nucleus
3b Late normoblast
3c Normoblast in mitosis
4 Hemolyzed red cells (ghosts)
5 Platelets
6 Small lymphocyte
7 Monocytes
8 Large lymphocytes
9 Megakaryocyte
10 Eosinophil leukocyte
11 Neutrophil leukocytes
12 Basophil leukocyte
13 Polychromatophil erythroblast
13a Hemocytoblast
14 Megaloblast
15 Eosinophil myelocyte
16 Neutrophil myelocyte
17 Neutrophil metamyelocyte

Reference: Best, C. H., and N. B. Taylor. 1961. The physiological basis of medical practice. Ed. 7. Williams and Wilkins, Baltimore.

IX. BIOLOGICAL REGULATORS AND TOXINS

89. ENZYMES

Part I. CATALYTIC ACTION

Catalytic Action (column B) and **Cofactors** (column F): ADP = adenosine diphosphate; AMP = adenosine-5'-monophosphate; ATP = adenosine triphosphate; CoA = coenzyme A; NAD^+ = nicotinamide adenine dinucleotide; $NADP^+$ = nicotinamide adenine dinucleotide phosphate. **Method** (column G): Chem = chemical; Col = colorimetric; Enzy = enzymatic; Mano = manometric; Pol = polariscopic; Phys = physical; Thun = Thunberg; Titr = titrimetric; Turb = turbidity. Figures (column G) are wavelengths used for measuring light absorption.

	Enzyme	Catalytic Action (Substrate → Product)	Conditions Suitable for Enzyme Action[1]					Occurrence
			pH	Substrate Concentration	Temp. °C	Cofactor	Method	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
1	Aceto-coenzyme A-kinase	ATP + acetate + CoA → acetyl CoA + AMP + pyrophosphate	7.5	0.005 *M*	37	Mg^{++}, K^+	Chem	Yeast
2	Acetylcholine esterase	Acetylcholine → acetate + choline	7.4	3 mg/ml	37	....	Mano	Liver, pancreas, brain, blood
3	Aconitase	Citric acid → *cis*-aconitic acid[2]	7.4	0.03 *M*	25	Fe^{++}	240 mμ	Tissues, bacteria, yeasts, seeds, leaves
4	Adenase	Adenine → hypoxanthine + NH_3	8.7	....	40	....	Chem	Muscle, milk, blood
5	Adenosinetriphosphatase	ATP → ADP + PO_4	7.5	1 mg P/ml	37	Ca^{++}	Chem	Brain, muscle, venoms, potatoes
6	Alcohol dehydrogenase	Ethanol → acetaldehyde	7.8	0.03%	20	NAD^+	Mano	Liver, kidney, brain, blood, yeasts, bacteria, higher plants
7	Aldolase	Fructose-1, 6-diphosphate → triosephosphates	9	0.01 *M*	38	Co^{++}, Fe^{++}, or Zn^{++}	Chem	Muscle, *Escherichia coli*, yeasts, higher plants
8	Amino acid carboxylase	Amino acid → amines + CO_2	4-5.5	0.001 *M*	30	Pyridoxal phosphate	Mano	Liver, kidney, pancreas, bacteria, higher plants
9	D-Amino acid oxidase	D-Amino acids + O_2 → α-keto acids + H_2O_2 + NH_3	8.6	0.01 *M*	38	....	Mano	Widespread (animals); fungi
10	L-Amino acid oxidase	L-Amino acids + O_2 → α-keto acids + H_2O_2 + NH_3	8.8	0.015 *M*	38	....	Mano	Liver, kidney, venoms, fungi, bacteria
11	Aminotripeptidase	Tripeptide → dipeptide + amino acid	8.0	0.05 *M*	39	....	Titr	Mucosa, muscle
12	α-Amylase (animal)	Starch or glycogen → dextrins + maltose	7	1%	37	NaCl	Chem	Liver, saliva, urine
13	α-Amylase (plant)	Starch or glycogen → dextrins + maltose	4.5-5.5	12 mg/ml	30	....	Chem	Bacteria, yeasts, cereals
14	β-Amylase (animal, plant)	Starch → dextrins + maltose	4-5	12 mg/ml	...	....	......	Cereals, soybeans, sweet potatoes
15	Amylophosphorylase	Dextrin + glucose-1-phosphate → starch or glycogen + phosphate	6.8	0.001 *M*	30	Starch or glycogen	Chem	Widespread (animals, plants)
16	Amylosucrase	Sucrose → "glycogen" + fructose	5.6	10 mg/ml	23	....	Chem	Bacteria
17	Apyrase	ATP → AMP + 2 phosphate	6.5	....	30	Ca^{++}	Chem	Liver, muscle, yeasts, tubers

/1/ Conditions vary with the method used and with the source of the enzyme. /2/ To isocitric acid.

continued

89. ENZYMES

Part 1. CATALYTIC ACTION

	Enzyme	Catalytic Action (Substrate → Product)	Conditions Suitable for Enzyme Action[1]: pH	Substrate Concentration	Temp. °C	Cofactor	Method	Occurrence
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
18	Arginase	L-Arginine → L-ornithine + urea	9.5	0.66%	38	Co^{++}, Mn^{++}	Mano	Liver, bacteria, fungi, seeds, spleen
19	Ascorbic acid oxidase	L-Ascorbic acid + O_2 → dehydroascorbate + H_2O	6.0	0.01 *N*	20	....	Mano	Widespread (plants)
20	Asparaginase	L-β-Asparagine → L-aspartic acid + NH_3	8	0.5 *M*	40	....	Chem	Liver, mucosa, bacteria, fungi, seeds
21	Aspartase	L-Aspartic acid → fumaric acid + NH_3	7-7.5	0.1 *M*	37	....	Chem	Bacteria, yeasts, leaves
22	Carbonic anhydrase	H_2CO_3 → CO_2 + H_2O	5-9	0.08 *M*	15	....	Mano	Erythrocytes, gastric mucosa
23	Carboxypeptidase	Peptide (free COOH) → amino acid + peptide	8.5	6% edestin	25	....	Titr	Pancreas (as xymogen)
24	Catalase	H_2O_2 → H_2O + O_2	6.8	0.01 *N*	0	....	Chem	Erythrocytes, liver, kidney, bacteria, higher plants
25	Chlorophyllase	Chlorophyll → chlorophyllide + phytol	5.9	1 mg/ml	25	$CaCl_2$	Chem	Bacteria, leaves, stems
26	Cholesterol esterase	Cholesterol esters → cholesterol + acids	5.3 or 7	....	...	....	......	Liver, kidney, spleen, intestinal mucosa, blood, pancreas, bacteria
27	Choline acetylase	Choline + acetyl CoA → acetylcholine	7	....	...	CoA, ATP	Chem	Brain, muscle, bacteria
28	Chymotrypsin	Proteins → polypeptides + amino acids	7.6	5% casein	38	....	Chem	Pancreas
29	Conjugase	Pteroylglutamate → pterine + glutamic acid	7-8	....	37	Ca^{++}	......	Pancreas, tissues, yeasts, tubers
30	Cytochrome-*c* oxidase	Ferro-cytochrome-*c* + O_2 → ferri-cytochrome-*c* + H_2O	7.2	0.0001 *M*	37	....	Mano	Widespread (animals, plants)
31	Cytochrome-*c* peroxidase	Ferro-cytochrome-*c* + H_2O_2 → ferri-cytochrome-*c* + H_2O	7.4	1.5×10^{-5} *M*	20	....	550 mμ	Yeasts
32	Cytochrome-*c* reductase	Ferri-cytochrome-*c* → ferro-cytochrome-*c*	7.3	2×10^{-5} *M*	25	$NADP^+$	550 mμ	Liver, yeasts
33	Deoxyribonuclease	Thymonucleic acid → nucleotides	6-7	0.5%	37	Mg^{++}, Mn^{++}	Phys	Intestinal mucosa, pancreas, seeds
34	Dextransucrase	Sucrose → dextran + fructose	5.6	10 mg/ml	23	....	Chem	Bacteria
35	Enolase	2-Phosphoglycerate → (enol) phosphopyruvate	7	0.1 mg P/ml	20	Mg^{++}, Mn^{++}, Zn^{++}	Chem	Muscle, yeasts, leaves
36	Esterase, simple	Ethyl butyrate → ethanol + butyrate	8.0	Saturated	20	....	Titr	Widespread (animals); seeds, fungi
37	Ficin	Proteins → amino acids and peptides?	5	....	35	H_2S, HCN, cysteine	......	Fig tree sap
38	Fructose-1, 6-diphosphatase	Fructose diphosphate + H_2O → fructose-6-phosphate + orthophosphate	8.8	0.02 *M*	25	Mg^{++}	340 mμ	Spinach
39	Fumarase	Fumaric acid → L(-)malic acid	6.6	0.025 *M*	40	....	Chem	Liver, muscle, bacteria, fungi, higher plants
40	β-Galactosidase (lactase)	Lactose → galactose + glucose	5.6	2.5%	38	....	Chem	Bacteria, seeds

/1/ Conditions vary with the method used and with the source of the enzyme.

continued

89. ENZYMES

Part I. CATALYTIC ACTION

	Enzyme	Catalytic Action (Substrate → Product)	Conditions Suitable for Enzyme Action[1] pH	Substrate Concentration	Temp. °C	Cofactor	Method	Occurrence
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
41	Glucose dehydrogenase	D-Glucose → D-gluconic acid	7.4	0.2 *M*	38	NAD^+ or $NADP^+$	Thun	Liver
42	Glucose oxidase (notatin)	D-Glucose + O_2 → gluconate + H_2O_2	6.0	1%	39	....	Mano	Fungi
43	Glucose-6-phosphate dehydrogenase	Glucose-6-phosphate → phosphogluconate	7.5	0.02 *M*	38	$NADP^+$	Mano	Blood, yeasts
44	α-Glucosidase (maltase)	Maltose → glucose	7.2	50 mg/ml	30	....	Pol	Intestinal mucosa, fungi, malt
45	β-Glucosidase	β-Glucosides → glucose + aglycon	4.4-5.0	1 mg/ml	30	....	Pol	Intestinal mucosa, liver, kidney
46	β-Glucuronidase	β-Glucuronide → glucuronate + alcohol	4.5	0.001 *M*	38	....	Col	Widespread (animals); bacteria, higher plants
47	Glutamate dehydrogenase	Glutamate → α-ketoglutarate + NH_3	8.2	0.0001 *M*	37	NAD^+ or $NADP^+$	340 mμ	Liver, kidney, muscle, brain
48	Glyoxalase	Methylglyoxal → lactate	7	1 mg/ml	25	Glutathione	Mano	Liver, kidney, muscle, blood, bacteria, fungi, seeds
49	Guanase	Guanine → xanthine + NH_3	8.7	Saturated	40	....	Chem	Liver, pancreas, spleen, kidney, seeds
50	Hexokinase	Hexose + ATP → hexosemonophosphate + ADP	7.5	0.001 *M*	30	Mg^{++}, Mn^{++}	Chem	Liver, muscle, kidney, brain, bacteria, yeasts, higher plants
51	Histaminase	Histamine → aldehyde + H_2O_2 + NH_3	6.8-7.6	0.01 *M*	37	....	Mano	Widespread (animals); bacteria, fungi
52	Histidase	Histidine → glutamate + formate + NH_3	8	0.01 *M*	38	....	Chem	Liver
53	Hyaluronidase	Hyaluronate → acetylglucosamine + glycuronate	7.0	0.1%	37	....	Phys	Spleen, testes, insects, venoms, bacteria
54	β-Hydroxybutyrate dehydrogenase	L-β-Hydroxybutyrate → acetoacetate	7	0.05 *M*	38	NAD^+	Mano	Widespread (animals, plants)
55	Invertase (sucrase, saccharase)	Sucrose → glucose + fructose	4.5	4 g/25 ml	20	....	Pol	Intestinal mucosa, invertebrates, fungi, bacteria, higher plants
56	Isocitratase	Isocitrate → succinate + glyoxylate	7.9	0.025 *M*	30	Mg^{++}	Chem	Aerobic bacteria
57	Isocitrate dehydrogenase	D-Isocitrate → α-ketoglutarate + CO_2	7.0	0.002 *M*	25	NAD^+, $NADP^+$, Mg^{++}, Mn^{++}	340 mμ	Widespread (animals, plants)
58	Lactate dehydrogenase	Lactate → pyruvate	9.3	0.02 *M*	20	NAD^+	Mano	Widespread (animals)
59	Lecithinase A	Lecithin → lysolecithin + fatty acid	7	Egg yolk	38	Ca^{++}	Chem	Liver, muscle, pancreas, venoms, mushrooms
60	Lecithinase B	Lysolecithin → glycerylphosphorylcholine + fatty acid	4	....	41	....	Chem	Liver, spleen, pancreas, brain, fungi, seeds, rice bran

/1/ Conditions vary with the method used and with the source of the enzyme.

continued

89. ENZYMES

Part I. CATALYTIC ACTION

	Enzyme	Catalytic Action (Substrate → Product)	Conditions Suitable for Enzyme Action[1] pH	Substrate Concentration	Temp. °C	Cofactor	Method	Occurrence
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
61	Leucylpeptidase	Leucyl peptides → leucine + other amino acids	8-9	0.05 *M*	40	Mg^{++}, Mn^{++}	....	Intestinal mucosa, leaves, malt, bacteria, fungi
62	Levansucrase	Sucrose → levan + glucose + fructose	5.0-5.8	5%	...	....	Chem	Bacteria
63	Lipase, pancreatic	Fats → glycerol + fatty acids	9	2.5 g/15 ml	30	$CaCl_2$	Titr	Pancreas
64	Lipase, seed	Fats → glycerol + fatty acids	4.7-5.0	....	...	Ca^{++}	....	Seeds
65	Lipoxidase	Linoleic acid, etc., → oxidized fatty acids	6.5	0.02%	25	....	Col	Intestinal mucosa, muscle, seeds
66	Luciferase	Luciferin + O_2 → oxidized luciferin + light	7.2	10^{-6} *M*	23	Mg^{++}, ATP	....	Insects, ostracods, bacteria, fungi
67	Lysozyme	Bacterial cells → lysed bacterial cells	5.3	Suspension	38	....	Turb	Nasal mucosa; latex of fig
68	Malate dehydrogenase	L(-)Malate → oxalacetate	7.2	0.025 *M*	37	NAD^+ or $NADP^+$	Thun	Brain, kidney, liver, muscle; widespread (plants)
69	Nucleoside phosphorylase	Inosine → hypoxanthine + ribose-1-phosphate	7.5	0.001 *M*	30	....	290 mμ	Spleen, lungs, liver, blood, intestinal mucosa; traces (plants)
70	Oxalacetic carboxylase	Oxalacetate → pyruvate + CO_2	5.0	0.5 mg/L	30	Mn^{++}	....	Liver, bacteria, seeds, leaves
71	Papain	Proteins, proteoses, etc. → amino acids	7.5	2%	30	HCN, H_2, S, cysteine	Col	Seeds, latex
72	Pectinesterase	Pectin → pectate + methanol	6.2	1%	30	....	Titr	Leaves, fruit, bacteria
73	Pectinase	Pectin → galacturonide	4.0	0.5%	25	....	Chem	Bacteria, fungi
74	Pepsin	Proteins → proteoses, peptones, amino acids	1.5-2.0	2%	20	....	Col	Gastric mucosa
75	Peroxidase, plant	H_2O_2 + pyrogallol, etc. → H_2O + purpurogallin, etc.	4.5-6.5	0.25%	20	....	Col	Widespread (plants)
76	Phosphocarboxyltransphosphorylase	1,3-Diphosphoglycerate + ADP → 3-phosphoglycerate + ATP	7.9	1 mg/ml	25	Mg^{++}	340 mμ	Muscle, yeasts
77	Phosphoenoltransphosphorylase	Phosphopyruvate + AMP → pyruvate + ATP	....	1.5 m*M*	38	Mg^{++}, K^+	....	Muscle, yeasts, higher plants
78	Phosphoglucomutase	Glucose-1-phosphate → glucose-6-phosphate	7.5-9.2	10^{-6} *M*	30	Co^{++}, Mg^{++}, Mn^{++}	Chem	Widespread (animals, plants)
79	Phosphoglyceromutase	3-Phosphoglycerate → 2-phosphoglycerate	7	10^{-5} *M*	24	....	Chem	Widespread (animals, plants)
80	Phosphomonoesterase I (alkaline)	β-Glycerophosphate → H_3PO_4 + glycerol	9.2	0.02 *M*	37	Mg^{++}	Chem	Widespread (animals); bacteria, fungi; none in higher plants
81	Phosphomonoesterase II (acid)	β-Glycerophosphate → H_3PO_4 + glycerol	5-6	0.05 *M*	37	....	Chem	Prostate, spleen, liver, bacteria, fungi, seeds, tubers
82	Phosphomonoesterase III	Monoesters of phosphate → H_3PO_4 + alcohols	3.4-4.2	....	...	....	....	Liver, spleen, fungi, seeds
83	Phosphomonoesterase IV	α-Glycerophosphate → H_3PO_4 + glycerol	5.2-6.2	....	...	Mg^{++}, Mn^{++}	Chem	Blood, bacteria, yeasts

/1/ Conditions vary with the method used and with the source of the enzyme.

continued

89. ENZYMES

Part I. CATALYTIC ACTION

	Enzyme	Catalytic Action (Substrate → Product)	Conditions Suitable for Enzyme Action[1] pH	Substrate Concentration	Temp. °C	Cofactor	Method	Occurrence
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
84	Phytase	Phytate → inositol + phosphate	5.5-7.8	0.1%	37	Mg^{++}	Chem	Blood, intestinal mucosa, fungi, seeds
85	Pyrophosphatase I	Pyrophosphate → phosphate	7.2-7.8	0.001 *M*	38	Mg^{++}, Mn^{++}	Chem	Widespread (animals); fungi, seeds
86	Pyruvic carboxylase	Pyruvate → acetaldehyde + CO_2	6.0	0.15 *M*	30	Thiamine pyrophosphate, Mg^{++}	Mano	Fungi, bacteria, seeds
87	Q-Enzyme	Amylose → amylopectin	7.0	....	21	....	....	Liver, muscle, seeds, tubers
88	Rennin	Casein → paracasein	5.8	Raw milk	40	....	Phys	Calf stomach
89	Ribonuclease	Ribonucleic acid → ribonucleotides	4-5	0.25 mg P/ml	25	....	Chem	Liver, spleen, pancreas, lungs, bacteria, higher plants
90	Succinate dehydrogenase	Succinate → fumarate	7.4	0.01 *M*	37	Cytochrome-*c*, ?	Thun	Widespread (animals, plants)
91	Sucrose phosphorylase	Sucrose + phosphate → fructose + glucose-1-phosphate	6.6	0.1 *M*	30	....	Chem	Bacteria
92	Synthetase, glycogen	$(Glucose)_n$ + uridine diphosphate glucose → $(glucose)_{n+1}$ + uridine diphosphate	8.4	0.005 *M*	37	....	Enzy	Animal tissue
93	Transaminase	Glutamate + oxalacetate → α-ketoglutarate + aspartate	7.5	0.02 *M*	40	....	Chem	Widespread (animals, plants)
94	Triosephosphate dehydrogenase	D-Glyceraldehyde-3-phosphate → 1, 3-diphosphoglycerate	8.6-9.0	0.0001 *M*	27	NAD^+	340 mμ	Widespread (animals, plants)
95	Trypsin	Proteins (especially denatured) → polypeptides and amino acids	8-9	2.2%	25	....	Col	Pancreatic juice
96	Tyrosinase	Catechol, etc. + O_2 → *o*-quinone, etc., + H_2O	5.5-7	2 mg/ml	25	....	Mano	Melanomas, skin; plants
97	Urease	Urea → CO_2 + NH_3	7.0	1.5%	20	....	Chem	Blood, gastric mucosa, insects, bacteria, fungi, seeds
98	Xanthine oxidase	Xanthine or aldehyde → uric or other acids	7.5	0.003 *M*	20	....	Mano	Liver, milk

/1/ Conditions vary with the method used and with the source of the enzyme.

Contributors: (a) Somers, G. Fred., (b) Perlman, D., (c) Campbell, Jack J. R.

References: [1] Boyer, P. D., H. Lardy, and K. Myrbäck, ed. 1959-63. The enzymes. Ed. 2. Academic Press, New York. [2] Dixon, M., and E. C. Webb. 1958. Enzymes. Academic Press, New York. [3] Sumner, J. B., and G. F. Somers, ed. 1953. Chemistry and methods of enzymes. Ed. 3. Academic Press, New York.

continued

Data are for enzymes in the crystalline state. *Abbreviations:* AMP = adenosine-5'-monophosphate; ADP = adeno-
NADP+ = nicotinamide adenine dinucleotide phosphate; NADPH = reduced NADP+; Tris = Tris(hydroxymethyl)amino-

	Common Name (Systematic Name)[1] [Code Number]	Source	Physical Properties: $S_{20,w}$[2] sec x 10^{13}	Physical Properties: $D_{20,w}$[2] $cm^2 sec^{-1}$ x 10^{-7}	Physical Properties: Molecular Weight	Physical Properties: Isoelectric Point[3] pH	Optimum pH
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
1	Adenylic deaminase (AMP aminohydrolase) [3.5.4.6]	Rabbit muscle	12.3	3.76	320,000	5.6	6.4[6]
2	Alcohol dehydrogenase (alcohol:NAD+ oxidoreductase) [1.1.1.1]	Bakers' yeast	6.72	4.70	150,000	5.4	
3		Horse liver	5.11	5.96	84,000	6.8	8.0
4	Aldolase (Ketose-1-phosphate aldehydelyase) [4.1.2.7]	Cattle liver	8.87[8]	5.20[8]	159,000	6.6-6.7	9.1-9.5[9]
5		Rabbit muscle	7.35	4.63	149,000	6.05	5-10
6	L-Amino acid oxidase (L-Amino acid:O_2 oxidoreductase, deaminating) [1.4.3.2]	Snake venom	6.8[10]	5.1[10]	130,000		7.2-7.5
7	α-Amylase (α-1,4-Glucan 4-glucanohydrolase) [3.2.1.1]	*Bacillus subtilis*	4.56[11] 6.47[12]	7.98[11] 5.72[12]	48,900[11] 96,900[12]		5.8-6.0
8	β-Amylase (α-1,4-Glucan maltohydrolase) [3.2.1.2]	Sweet potato	8.9	5.77	152,000	4.74-4.79	4-5
9	Carboxypeptidase A [3.4.2.1]	Cattle pancreatic juice	3.07	8.82	34,440	5.95[13]	7.4[14]
10	Catalase (H_2O_2:H_2O_2 oxidoreductase) [1.11.1.6]	Cattle liver	11.3 11.15	4.5 4.1	225,000 244,000	5.7	4-8.5
11	Chymotrypsin [3.4.4.5]	Cattle pancreas	2.56	10.2	22,500 25,000	8.1-8.6[18]	7-9
12	Creatine kinase (ATP:creatine phosphotransferase) [2.7.3.2]	Rabbit muscle	5.0	5.78	81,000	6.0-6.1	9.0[17] 6-7[18]
13	Crotonase (L-3-Hydroxyacyl-CoA hydrolase) [4.2.1.17]	Cattle liver	7.84		210,000[20]		9.0[21]
14	Enolase (D-2-Phosphoglycerate hydrolase) [4.2.1.1]	Yeast	5.9	8.08	67,000		7.8
15	Fumarase (L-Malate hydro-lyase [4.2.1.2]	Swine heart	9.09	4.05	220,000	7.35[22]	6.3
16	β-Galactosidase (β-D-Galactoside galactohydrolase) [3.2.1.23]	*Escherichia coli*	16.24	2.12	750,000		7.3[24]
17	Glucose oxidase (β-D-Glucose:O_2 oxidoreductase) [1.1.3.4]	*Penicillium amagasakiense*	7.93	5.02	154,000	4.35	5.6-5.8
18	Glucose-6-phosphate dehydrogenase (D-Glucose-6-phosphate:NADP+ oxidoreductase)	Brewers' yeast	6.3[11] 9.3[12]		100,000[11,21] 200,000[12,21]		8.5
19	Glutamate dehydrogenase (L-Glutamate:NADP+ oxidoreductase)	Cattle liver	26.6	2.54	1,000,000	4-5	8.3-8.5
20	Glyceraldehyde-3-phosphate dehydrogenase (D-Glyceraldehyde-3-phosphate:NAD+ oxidoreductase)	Rabbit muscle	7.01	5.46	120,000	6-8 in phosphate[16]	8.5-9.0

/1/ Systematic names and code numbers recommended in the *Report of the Commission on Enzymes of the Inter-*
diffusion ($D_{20,w}$) coefficients are for data normalized to standard conditions of water at 20°C and extrapolated to
lecular activity is defined as the number of molecules of substrate transformed per minute by one molecule of en-
(Michaelis constant) = $\frac{K_{-1} + K_{+2}}{K_{+1}}$, where K_{+1} = velocity constant for formation of the enzyme-substrate complex,
for the breakdown of the enzyme-substrate complex into products. /6/ In 0.1 *M* succinate. /7/ V_{max} (maximal
/9/ In glycylglycine. /10/ Not extrapolated to zero protein concentration. /11/ Monomer. /12/ Dimer. /13/ Deter-
approximately 30,000. /16/ Depends on ionic strength of the buffer. /17/ Forward reaction. /18/ Reverse reaction.
/21/ Approximately. /22/ In 0.1 *M* Tris. /23/ K_m's independent of pH but dependent on ionic strength. /24/ Buffer
second order rate constant.

sine diphosphate; ATP = adenosine triphosphate; CoA = coenzyme A; NAD^+ = nicotinamide adenine dinucleotide; methane.

Kinetic Properties								Reference	
Molecular Activity				Michaelis Constant					
Substrate	Temp. °C	pH	Value[4]	Substrate	Temp. °C	pH	K_m[5] moles/liter		
(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)	(P)	
AMP (4.5×10^{-5} M, calculated V_{max})[7]	30	6.4	18,300	AMP	30	6.4	1.43×10^{-3}	B,66;C-F,67;G-O,68	1
Ethanol	26	7.9	27,000	Ethanol	Room	8.2	1.4×10^{-2}	B,96;C-F,45;H-K,20; L-O,28	2
				Ethanol	23.5	8.0	2.5×10^{-4}	B,11;C,D,31;E,30;F, 25;G,L-O,132	3
Fructose-1, 6-diphosphate	30	9.4	400	Fructose-1, 6-diphosphate	30	9.4	4×10^{-3}	B,G-O,91;C-F,92	4
Fructose-1, 6-diphosphate	30	7.5	4,200	Fructose-1, 6-diphosphate	30		5×10^{-5}	B,126;C-E,127;F,136; G,76;H-K,7;L,M,O, 134	5
L-Leucine	38	7.45	2,800					B,G,144;C-E,12;H-K, 144,145	6
Maltose	25	6.0	86,000/48,900 g enzyme	Glucosidic bonds	20-30		$1\text{-}5 \times 10^{-3}$	B,H-K,33;C-E,34;G, 77;L,M,O,12	7
Glycosidic linkages	30	4.8	250,000					B,G,5;C-F,32;H-K, 12,32	8
Chloroacetyl-α-β-phenyllactic acid	25	7.5	7,240	Benzenesulfonyl glycylphenyl-alanine	25	7.5	1.4×10^{-2}	B,2;C,105;D,95,105; E,109;F,95;G,106; H-K,81;L-O,110	9
H_2O_2			10^7[15]					B,118;C,99,120;D,98, 119;E,99,119;F,143; G,H,K,19	10
Benzoyl-L-phenyl-alanine methyl-ester	25	7.8	3,000	Acetyl-L-tyrosine amide	25	7.8	2.7×10^{-2}	B,62;C,104;D,102;E, 12,104;F,1;G,44; H-O,81	11
ATP, creatine ADP, creatine	30 30	9 7	16,000 100,000	ATP Creatine ADP Creatine phosphate	30 30	9 7	5×10^{-4}[19] 1.6×10^{-2}[19] 8×10^{-4}[19] 5×10^{-3}[19]	B,57;C-F,85;G-O,58	12
Crotonyl CoA	25	7.5	730,000	Crotonyl CoA			1.56×10^{-4}	B,112;C,E,12;G-L,O, 138	13
Phosphoglyceric acid		7.4	5,400					B,141;C,12,73;D,E,H, J,K,12;G,147	14
Fumarate	20	7.3	100,000	Fumarate	25		2×10^{-6} to 4×10^{-5}[23]	B,37,74;C,37;D,17;E, 37,49;F,103;G,36; H-K,74;L,M,O,38	15
o-Nitrophenyl-β-D-galactoside	20	7.6	133,500 (V_{max})[7]	o-Nitrophenyl-β-D-galactoside	20	7.6	1.61×10^{-4}	B,48,140;C-E,48;G-O,12	16
O_2	30		17,000[25]	Glucose	30		1.5×10^{-2}	B-E,G-I,K,64;F,12; L,M,O,63	17
Glucose-6-phosphate	30	8.0	67,600/ 100,000 g enzyme	Glucose-6-phosphate	25	8.0	$2.0\text{-}5.8 \times 10^{-5}$	B,H-K,88;C,E,12;G, 41;L-O,41,69	18
Glutamate			1,000 mole/ 1,000,000 g enzyme	Glutamate	25	8.0	1.8×10^{-3}	B,90,115,116;C-H,K, 90;L-O,12	19
Glyceraldehyde-3-phosphate and NAD^+	27	8.6	10,300/min/ mole enzyme[28]	Glyceraldehyde-3-phosphate	27	8.6	$3.9\text{-}5.1 \times 10^{-5}$	B,G,22;C-E,127;F, 137;H-O,20	20

national Union of Biochemistry, 1961, Pergamon Press, New York. /2/ Values for sedimentation ($S_{20,w}$) and zero protein concentration. /3/ Apparent values determined from electrophoretic mobility measurements. /4/ Mo-zyme at optimal substrate concentration. Values pertain to the molecular weight given in column E. /5/ K_m
K_{-1} = velocity constant for the dissociation of this complex into substrate and enzyme, and K_{+2} = velocity constant
velocity) = $v(1+K_m/S)$, where v is the measured velocity at a substrate concentration S. /8/ Determined at 25°C. mined at 0.2 ionic strength. /14/ In Veronal buffer. /15/ Hypothetical value calculated from a "katalasefähigkeit" of /19/ K_m's are apparent constants for total substrates under specified conditions. /20/ Determined by light scattering. used was 0.05 *M* NaCl and 0.05 *M* Tris. /25/ Derived from Q_{O_2} = 148,000 µl O_2 per mg per hour. /28/ Calculated as

continued

	Common Name (Systematic Name)[1] [Code Number]	Source	Physical Properties: $S_{20,w}$[a] sec x 10^{13}	Physical Properties: $D_{20,w}$[a] cm^2sec^{-1} x 10^{-7}	Physical Properties: Molecular Weight	Physical Properties: Isoelectric Point[3] pH	Optimum pH
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
21	Glycerokinase (ATP:glycerol phosphotransferase) [2.7.1.30]	*Candida mycoderma*	10.87	4.2	251,000	4.6	
22	α-Glycerophosphate dehydrogenase (L-Glycerol-3-phosphate:NAD+ oxidoreductase) [1.1.1.8]	Rabbit muscle	4.9	5.1	78,000		7.5[27]
23	Glycogen phosphorylase[28] (α-1,4-Glucan:orthophosphate glucosyltransferase) [2.4.1.1]	Rabbit muscle	13.2	2.6	495,000	<5.8	6.8
24	Hexokinase (ATP:D-hexose 6-phosphotransferase) [2.7.1.1]	Bakers' yeast	3.1	2.9	96,600	4.5-4.8	
25	Homoserine dehydratase (L-Homoserine hydro-lyase, deaminating) [4.2.1.15]	Rat liver	8.9	4.1	190,000		8.0
26	Lactate dehydrogenase (L-Lactate:NAD+ oxidoreductase) [1.1.1.27]	Cattle heart	7.0	5.3	135,000	4.5-4.8	
27	Myokinase[29] (ATP:AMP phosphotransferase) [2.7.4.3]	Rabbit muscle	2.30[8]	1.00[8]	21,279	6.1	8.0
28	Old yellow enzyme (NADPH:(acceptor) oxidoreductase) [1.6.99.1]	Brewers' yeast	5.82	5.54	102,000	5.[illegible]	
29	Papain [3.4.4.10]	Papaya latex	2.42	10.27	20,700	8.75	5-10
30	Pepsin [3.4.4.1]	Cattle stomach mucosa	3.20	8.71	35,700	<1.0	2-4[30]
31	Peroxidase (Donor:H_2O_2 oxidoreductase) [1.11.1.7]	Horseradish	3.48		39,800	7.2	
32	Phosphoglucoisomerase (D-Glucose-6-phosphate ketolisomerase) [5.3.1.9]	Rabbit muscle	7.5	5.3	140,000		9
33	Phosphoglucomutase (D-Glucose-1,6-diphosphate:D-glucose-1-phosphate phosphotransferase) [2.7.5.1]	Rabbit muscle	3.69	4.83	74,000		7.5
34	Phosphoglycerate kinase (ATP:D-3-phosphoglycerate 1-phosphotransferase) [2.7.2.3]	Brewers' yeast	3.20		34,000		
35	Phosphoglyceromutase (D-2,3-Diphosphoglycerate:D-2-phosphoglycerate phosphotransferase) [2.7.5.3]	Bakers' yeast	6.30	5.29	112,000	5.0-5.5	5.9 or 7.0[33]
36	Pyrophosphatase, inorganic (Pyrophosphate phosphohydrolase) [3.6.1.1]	Bakers' yeast	4.4	6.8	63,000	4.75	7.0
37	Pyruvate kinase (ATP:pyruvate phosphotransferase)	Rabbit muscle	10.04	3.96	237,000	6.6	
38	Ribonuclease (Polyribonucleotide:2-oligoribonucleotidotransferase, cyclyzing) [2.7.7.16]	Cattle pancreas	1.87	11.14	13,683	9.604[34]	7.2-8.2
39	Transketolase (D-Sedoheptulose-7-phosphate:D-glyceraldehyde-3-phosphate glycolaldehydetransferase) [2.2.1.1]	Bakers' yeast	7.34	5.0	140,000		7.6

/1/ Systematic names and code numbers recommended in the *Report of the Commission on Enzymes of the Inter* diffusion ($D_{20,w}$) coefficients are for data normalized to standard conditions of water at 20°C and extrapolated tc lecular activity is defined as the number of molecules of substrate transformed per minute by one molecule of en- (Michaelis constant) = $\frac{K_{-1} + K_{+2}}{K_{+1}}$, where K_{+1} = velocity constant for formation of the enzyme-substrate complex, for the breakdown of the enzyme-substrate complex into products. /7/ V_{max} (maximal velocity) = $v(1+K_m/S)$, where *M* phosphate. /28/ Composed of two molecules of phosphorylase *b*, each with a molecular weight of 242,000. phate concentration. /32/ Valid only under conditions specified in reference 14. /33/ Depending upon type of assay.

ENZYMES

KINETIC PROPERTIES

Kinetic Properties								Reference	
Molecular Activity				Michaelis Constant					
Substrate	Temp. °C	pH	Value[4]	Substrate	Temp. °C	pH	K_m[5] moles/liter		
(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)	(P)	
Glycerol			100,000	Glycerol			6×10^{-5}	B-F,H,K,L,O,10	21
Dihydroxyacetone phosphate	20	7	20,670	α-Glycerophosphate	23	7.0	1.1×10^{-4}	B,H-K,6;C-E,135;G, L-O,148	22
Glucose-1-phosphate	30	6.7	40,000	Glucose-1-phosphate	30	6.8	5×10^{-3}	B,43;C-E,51,52;F, 42;G,20;H-O,21	23
Glucose	30	8	55,000	D-Glucose	28	7.6	1.67×10^{-4}	B,20,61;C-F,61;H-K, 20;L-O,39	24
Homoserine			6,400 (V_{max})[7]	Homoserine			2×10^{-2}	B-E,75;G,H,K,L,O, 12	25
Pyruvate	Room	7.0	37,000	Lactate	28.5	7.0	1.7×10^{-2}	B,114;C-F,79;H-K, 80;L-O,146	26
AMP (formation of ATP)	25	8.0	28,000	ATP	25	8.0	3.3×10^{-4}	B,83;C,D,F,84;E,72; G-O,82	27
O_2	37	7.4	155	$NADP^+$			0.9×10^{-5}	B,131;C-E,30;F,128; H-L,O,55	28
Benzoyl-L-argininamide	39	5.5	$2.7\text{-}6 \times 10^{-6}$/mole enzyme	Benzoyl-L-argininamide	38	6	3.9×10^{-2}	B,H-K,54;C-F,107; G,108;L-O,113	29
Carbobenzoxy-L-glutamyl-L-tyrosine ethyl ester	38	4.0	0.183	Carbobenzoxy-L-glutamyl-L-tyrosine ethyl ester	32	4.0	1.78×10^{-3}	B,46;C-E,29;F,93; G,89;H-K,15;L-O, 12	30
				H_2O_2	25-30	4.7	10^{-8}	B,129;C,E,16;F,130; L-O,18	31
Glucose-6-phosphate	30	8.0	77,000	Glucose-6-phosphate	30	8.0	3×10^{-5}	B,H-K,86;C-E,87;G, 20;L-O,50	32
Glucose-1-phosphate	30	7.5	12,400	Glucose-1-phosphate			10^{-5}[21,31]	B,G,78;C-E,53;H-L, O,94	33
ATP	25	6.9	110,000	ATP			1.1×10^{-4}[32]	B,H-L,O,14;C,E,65	34
D-2-Phosphoglycerate	30	7.0	98,000	2-Phosphoglycerate			$<10^{-4}$	B,97;C-L,O,20	35
Pyrophosphate			60,000					B,F-H,K,60;C-E,100	36
Pyruvate	25	7.5	57,000-66,000	Phosphoenolpyruvate	30	7.4	7×10^{-5}	B,8,133;C-F,142;H-K,12;L-O,71	37
Ribonucleic acid	25	5.0	7.5 moles phosphate liberated/mole enzyme					B,G,59;C,D,40;E, 101;F,125;H-K,70	38
Xylulose-5-phosphate and ribose-5-phosphate			3,400	Xylulose-5-phosphate (with 0.005 *M* R-5-P) Ribose-5-phosphate (with 0.0019 *M* xylulose-5-P)			2.1×10^{-4} 4×10^{-4}	B,27,111;C-E,H,K, 12;G,L,O,26	39

national Union of Biochemistry, 1961, Pergamon Press, New York. /2/ Values for sedimentation ($S_{20,w}$) and zero protein concentration. /3/ Apparent values determined from electrophoretic mobility measurements. /4/ Mo- zyme at optimal substrate concentration. Values pertain to the molecular weight given in column E. /5/ K_m

K_{-1} = velocity constant for the dissociation of this complex into substrate and enzyme, and K_{+2} = velocity constant

v is the measured velocity at a substrate concentration S. /8/ Determined at 25°C. /21/ Approximately. /27/ In 0.2

/29/ Adenylate kinase. /30/ With protein; pH 4 with synthetic substrates. /31/ K_m depends on glucose-1,6-diphos-

/34/ Isoelectric point value is that of the isoionic point in 0.001 *M* KCl.

continued

	Common Name (Systematic Name)[1] [Code Number]	Source	Physical Properties: $S_{20,w}$[3] sec x 10^{13}	$D_{20,w}$[3] $cm^2 sec^{-1}$ x 10^{-7}	Molecular Weight	Isoelectric Point[3] pH	Optimum pH
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
40	Trypsin [3.4.4.4]	Cattle pancreas	2.50	9.40	23,800	10.5	7-8
41	Tyrosinase (*o*-Diphenol:O_2 oxidoreductase) [1.10.3.1]	*Neurospora crassa*	4.3	10.7	33,000	6-8	6-8
42	Urease (Urea amidohydrolase) [3.5.1.5]	Jack bean meal	18.6	3.46	483,000	5.0-5.1	8.0
43	Xanthine oxidase (Xanthine:O_2 oxidoreductase) [1.2.3.2]	Milk	11.4	3.6	290,000	5.3-5.4	8.3

/1/ Systematic names and code numbers recommended in the *Report of the Commission on Enzymes of the Inter-*
diffusion ($D_{20,w}$) coefficients are for data normalized to standard conditions of water at 20°C and extrapolated to
lecular activity is defined as the number of molecules of substrate transformed per minute by one molecule of en-
(Michaelis constant) = $\frac{K_{-1} + K_{+2}}{K_{+1}}$, where K_{+1} = velocity constant for formation of the enzyme-substrate complex,
for the breakdown of the enzyme-substrate complex into products.

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Kinetic Properties								Reference	
Molecular Activity				Michaelis Constant					
Substrate	Temp. °C	pH	Value[4]	Substrate	Temp. °C	pH	K_m[5] moles/liter		
(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)	(P)	
Benzoyl-L-arginine ester	25	7.7	1,600	Benzoyl-L-arginine ester	25	8.0	8×10^{-5}	B,62;C,24;D-F,23; G,20;H-O,81	40
3,4-Dihydroxy-L-phenylalanine	30	6.0	19,600	Tyrosine	30	6.0	8×10^{-4}	B-F,H-K,35;G,124; L-O,47	41
Urea	20	7.0	460,000	Urea	21	8.0	4×10^{-3}	B,117;C-E,121;F, 122;G,L-O,139;H-K,23	42
				Xanthine			ca. 10^{-6}	B,3,56;C-F,4;G,9;L, P,13	43

national Union of Biochemistry, 1961, Pergamon Press, New York. /2/ Values for sedimentation ($S_{20,w}$) and zero protein concentration. /3/ Apparent values determined from electrophoretic mobility measurements. /4/ Mozyme at optimal substrate concentration. Values pertain to the molecular weight given in column E. /5/ K_m K_{-1} = velocity constant for the dissociation of this complex into substrate and enzyme, and K_{+2} = velocity constant

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Part III. CHEMICAL

Data are for crystalline or electrophoretically homogeneous enzymes.

	Enzyme	Source	Elements: Carbon	Hydrogen	Nitrogen	Sulfur	Phosphorus	Other	Amino N
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
1	Alcohol dehydrogenase	Yeast	52.8	6.96	16.53	1.21	......	Zn, 0.218	....
2	Aldolase	Rabbit muscle	.....	....	16.8	....	......	....	....
3	α-Amylase	Swine pancreas	49.46	7.18	15.52	1.33	0.05	....	....
4	β-Amylase	Sweet potato	.....	....	15.1	....	......	....	0.83
5	Carbonic anhydrase	Mammalian red cells	.....	....	16.1	0.34	......	Zn, 0.21	....
6	Carboxypeptidase	Cattle pancreas	52.6	7.2	14.4	0.47	0	Zn, 0.182	....
7	Catalase	Horse blood	.....	....	16.8	....	......	Fe, 0.093	....
8		Horse liver	.....	....	16.8	....	......	Fe, 0.093	....
9	α-Chymotrypsin	....	50.0	7.06	15.5	1.85	0	Cl, 0.16	1.22
10	β-Chymotrypsin	....	.....	....	16.24	1.56	......	....	1.31
11	γ-Chymotrypsin	....	.....	....	16.00	1.59	......	....	1.34
12	Chymotrypsinogen	Cattle pancreas	50.6	7.0	15.8	1.9	0	Cl, 0.17	0.97
13	Chymotrypsinogen A	....	.....	....	.....	....	......	....	....
14	Cytochrome-c[4]	Cattle heart	52.52	7.76	15.36	1.47	0	Fe, 0.43	....
15	Deoxyribonuclease	Cattle pancreas	50.16	6.91	14.88	1.09	0	....	....
16	Enolase	....	53.62	7.55	17.34	0.38	0	....	....
17	D-Glyceraldehyde phosphate dehydrogenase[5]	Rabbit muscle	.....	....	.....	....	......	....	....
18		Yeast	52.54	7.51	16.41	1.08	Trace	....	....
19	Hexokinase	Yeast	52.16	7.08	15.62	0.91	0.11	....	....
20	Lecithinase	....	50.77	6.41	15.88	4.0	......	....	....
21	Lipoxidase	....	.....	....	.....	....	......	....	....
22	Lysozyme[5]	....	.....	....	18.6	2.53	......	....	0.74
23	Old yellow enzyme	Yeast	51.4	7.07	16.27	0.48	0.043	....	....
24	Papain[5]	....	.....	....	16.1	1.2	0	....	....
25	Pepsin[5]	Cattle	51.7	6.86	14.6	0.94	0.09	....	0.162

/1/ Determined after oxidation to cysteic acid; one molecule of cysteic acid is formed from one-half of the sym- between cysteine and cystine, unless otherwise indicated. /2/ Cysteine plus cystine. /3/ Cystine. /4/ Values for given as number of amino acid residues per molecule of enzyme.

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COMPOSITION

Values are grams per 100 grams enzyme, unless otherwise indicated.

Amino Acids																			Reference	
Alanine	Arginine	Aspartic Acid	Cysteine	Cystine ½	Glutamic Acid	Glycine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Proline	Serine	Threonine	Tryptophan	Tyrosine	Valine		
(J)	(K)	(L)	(M)	(N)	(O)	(P)	(Q)	(R)	(S)	(T)	(U)	(V)	(W)	(X)	(Y)	(Z)	(A')	(B')	(C')	
....	....	....	....	....	....	....	....	....	...	....	....	....	....	....	....	....	...	...	5	1
8.56	6.33	9.7	....	1.12	11.4	5.61	4.21	7.87	11.5	9.54	1.17	3.06	5.71	6.57	7.1	2.31	5.31	7.40	5,31	2
....	....	....	....	....	....	....	....	....	...	....	....	....	....	....	....	....	...	...	6	3
....	6.0	....	....	0.79[a]	....	....	....	....	...	....	4.32	....	....	....	....	....	7.0	...	2	4
....	....	....	....	1.3	....	....	....	....	...	....	....	....	....	....	....	....	4.1	...	19,24	5
5.16	5.06	11.7	....	1.40	10.7	5.06	3.47	7.65	9.41	7.81	0.44	7.16	3.66	10.1	9.21	3.62	10.3	5.58	1,26,30	6
....	8.75	16.5	....	1.65[3]	10.9	....	4.17	....	...	7.50	....	....	....	....	....	....	6.0	...	3	7
....	8.90	16.5	....	1.85[3]	10.3	....	3.86	....	...	6.91	....	....	....	....	....	....	5.8	...	3	8
....	....	....	1.22	3.66	....	....	1.26	....	9.1	....	1.25	....	....	....	11.2	5.81	2.83	...	21	9
....	....	....	1.29	3.51	....	....	1.22	....	9.4	....	1.29	....	....	....	10.6	6.40	2.87	...	21	10
....	....	....	1.27	3.59	....	....	1.26	....	8.5	....	1.28	....	....	....	10.7	6.27	3.09	...	21	11
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...	21	12
22	4	8	....	10	3	23	2	10	19	13	2	6-7	9	30	23	7	4	22	4	13
....	5.6	....	....	1.4	....	....	6.3	....	....	30.8	....	....	....	....	....	1.4	3.5	...	28	14
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...	15	15
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...	33	16
8.5	5.2	13.9	1.1	....	8.2	7.0	4.5	6.4	6.9	10.3	3.7	6.3	4.1	6.1	7.6	2.1	4.6	10.8	5	17
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...	22	18
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...	17	19
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...	25	20
....	4.7	6.2	0	0	10.4	6.3	3.6	8.1	11.4	7.8	1.8	4.9	5.1	....	8.9	0.41	6.2	7.8	12	21
12	11	21	....	8	5	12	1	6	8	6	2	3	2	10	7	6	3	6	7,9	22
....	8.25	....	....	0.34	....	7.1	2.75	....	....	13.7	....	5.75	....	....	....	4.86	7.75	...	14	23
13	10	17	....	6	17	23	2	10	10	9	....	4	9	11	7	5	17	15	4	24
18	2	44	....	6	27	38	1	27	28	1	5	14	15	44	28	6	18	21	4,21	25

metrical cystine molecule or from one molecule of cysteine. The values in this column, therefore, do not distinguish
amino acids (columns J-B') are given as percent of total nitrogen. /5/ Values for amino acids (columns J-B') are

continued

	Enzyme	Source	Elements: Carbon	Hydrogen	Nitrogen	Sulfur	Phosphorus	Other	Amino N
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
26	Pepsin[5]	Salmon	51.9	6.48	15.62	1.58	0.03	....	....
27	Pepsinogen	....	52.8	6.88	15.9	0.09	.....	....	....
28	Peroxidase	Horseradish	47.0	7.35	13.2	0.43	.....	Fe, 0.13	....
29	Phospho-enoltransphosphorylase	Man	53.35	7.30	17.40	1.60	0.06	....	....
30	Phosphorylase	Rabbit muscle	.....	....	16.5	....	0.027	....	....
31	Pyrophosphatase	Yeast	54.46	7.36	16.25	0.14	0	....	0.86
32	Rennin	....	51.4	7.19	14.51	1.46	0.04	Cu, 0.0035	1.11
33	Ribonuclease[5]	....	48.2	6.2	16.1	1.1	Trace	....	....
34	Trypsin	....	50.2	6.6	16.13	1.1	0	Cl, 2.85	....
35	Trypsinogen	....	50.1	6.9	15.3	1.1	.....	....	....
36	Urease	Jack bean	51.6	7.1	16.0	1.2	.....	Cu, 0.001	....

/1/ Determined after oxidation to cysteic acid; one molecule of cysteic acid is formed from one-half of the sym- between cysteine and cystine, unless otherwise indicated. /5/ Values for amino acids (columns J-B') are given as

Contributors: (a) Tupper, Ronald, and Watts, R. W. E., (b) Dianzani, Mario U., (c) Corley, Ralph C.

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90. HORMONES:

Data are for man, unless otherwise specified. **Properties** (column B): MW = molecular weight; MP = melting point; insoluble; s. = soluble; sl. = slightly; v. = very. *Symbols* (columns D, G-I): ↑ = increased; ↓ = decreased.

	Name; Synonyms; Chemical Formula; (Systemic Name)	Properties	Sources	Assay Methods	Metabolites
	(A)	(B)	(C)	(D)	(E)
	Adenohypophysis				
1	Adrenocorticotropin; adrenotropin, adrenocorticotropic hormone, ACTH, corticotropin	MW = 4,520 (cattle); amino acid no. = 39; one peptide chain, unbranched; IEP = 4.7-4.8; $S_{20,w}$ = 2.08; s. water, 60-70% alcohol	Adenohypophysis; synthetic tricosapeptide has full activity	Adrenal repair, wt maintenance (hypophysectomized rat); ↓ adrenal ascorbic acid (hypophysectomized rat); urinary excretion of corticoids (guinea pig)	Not definitely known; probably similar to other polypeptides; half-life of ACTH in blood is 3-5 min

ENZYMES

COMPOSITION

Amino Acids																			Reference	
Alanine	Arginine	Aspartic Acid	Cysteine	Cystine[1] $\frac{1}{2}$	Glutamic Acid	Glycine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Proline	Serine	Threonine	Tryptophan	Tyrosine	Valine		
(J)	(K)	(L)	(M)	(N)	(O)	(P)	(Q)	(R)	(S)	(T)	(U)	(V)	(W)	(X)	(Y)	(Z)	(A')	(B')	(C')	
....	....	....	....	....	....	....	....	....	...	....	....	....	....	....	....	....	...	...	20	26
....	....	....	....	....	....	....	....	....	...	....	....	....	....	....	....	....	...	...	21	27
....	6.91	....	....	....	....	....	0.71	....	...	4.06	....	....	....	....	....	....	...	...	29	28
....	....	....	....	....	....	....	....	....	...	....	....	....	....	....	....	....	...	...	13	29
4.79	11.6	9.3	....	0.45	13.4	3.8	3.3	6.5	10.5	7.2	2.7	6.2	4.7	3.05	4.24	2.0	5.9	7.3	8,32	30
4.9	3.3	12.1	....	....	9.7	2.9	2.2	8.9	6.0	10.9	1.3	6.2	6.4	3.1	4.8	3.6	6.0	4.1	11,16	31
....	....	....	....	....	....	....	....	....	...	....	....	....	....	....	....	....	...	...	10	32
12	4	5	....	8	5	3	4	3	2	10	4	3	4	15	10	....	6	9	21,23	33
....	....	....	....	....	....	....	....	....	...	....	....	....	....	....	....	3.65	7.8	...	18,21	34
....	....	....	....	....	....	....	....	....	...	....	....	....	....	....	....	....	...	...	18	35
....	....	....	....	....	....	....	....	....	...	....	....	....	....	....	....	....	...	...	27	36

metrical cystine molecule or from one molecule of cysteine. The values in this column, therefore, do not distinguish number of amino acid residues per molecule of enzyme.

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VERTEBRATES

IEP = isoelectric point; $S_{20,w}$ = sedimentation coefficient; $D_{20,w}$ = diffusion coefficient; $[\alpha]_D$ = refractive index; i. =

Targets	Principal Effects	Effect of Deficiency (-) Excess (+)	Secretion Inhibited by (I) Stimulated by (S)	Reference	
(F)	(G)	(H)	(I)	(J)	
Adenohypophysis					
Adrenal cortex; mitochondria and microsomes in most tissues; melanocytes	↓ lipid and ascorbic acid content of adrenal cortex; ↑ secretion of adrenal cortical hormones; ↑ oxidative phosphorylation, protein synthesis, glycolysis, synthesis of steroid hormones; ↑ fat transport and oxidation, muscle glycogen, amino acid metabolism	(-): adrenal cortex atrophy and hypofunction; ↓ response to stress (+): adrenal cortex hyperfunction	(I) blood level of cortisol; servo or feedback mechanism (S) stress, acting thru hypothalamus, plus corticotropin-releasing factors from adenohypophysis	3,7,21, 22,24, 26,27	1

continued

	Name; Synonyms; Chemical Formula; (Systemic Name)	Properties	Sources	Assay Methods	Metabolites
	(A)	(B)	(C)	(D)	(E)
	Adenohypophysis				
2	Follicle-stimulating hormone; FSH	MW = 29,000-30,000; IEP = 5.1-5.2; stable pH 7-8, 30 min at 75°C; s. water, 50% acetone, 70% alcohol, 50% dioxane, $\frac{1}{2}$-saturated $(NH_4)_2SO_4$	Adenohypophysis (especially sheep, swine); urine (castrates); serum (pregnant mare)	Follicular growth (hypophysectomized rat); ↑ wt of ovary and uterus (hypophysectomized, immature ♀ rat); ↑ uterine wt or hyperemia (immature mouse)	FSH-like protein
3	Growth hormone; GH, somatotropin	MW = 27,000[1]; IEP = 4.9[1]; $D_{20,w}$ = 7.15 x 10^{-7}; viscosity coefficient = 7.64; s. salt solution; sl. s. water; HNO_2 and acetylation destroy	Adenohypophysis (various species); plasma in children, 85-570 mg GH per ml	↑ tail length, tibial epiphyseal cartilage (hypophysectomized rat); body growth (hypophysectomized rat); inhibition of hemagglutination of erythrocytes sensitized to tannic acid and titrated with human GH; radioactivity of I^{131}-labeled GH unbound to anti-GH immune serum	Unknown; probably similar to other polypeptides
4	Luteinizing hormone; LH, interstitial-cell-stimulating hormone, ICSH	Sheep: MW = 30,000, IEP = 4.6, $S_{20,w}$ = 3.6 x 10^{-13}; swine: IEP = 7.45, $S_{20,w}$ = 6.8 x 10^{-13}; s. water, 40% alcohol, dilute salt solution	Adenohypophysis (especially sheep, swine)	Interstitial cell repair (hypophysectomized mouse, rat); regeneration of breast feathers (weaver finch); ↑ wt of ventral prostate (hypophysectomized rat); ↑ testes wt (pigeon); ↓ ascorbic acid in ovaries (rat)	
5	Lactogenic hormone; LTH, luteotropin, galactin, prolactin	MW = 24,100-26,000; IEP = 5.5-5.73; $D_{20,w}$ = 9 x 10^{-7}; viscosity coefficient = 6.65; $[\alpha]_D^{25°}$ = -40.5°; s. acid alcohol, methyl alcohol; sl. s. water, dilute salt solution; one peptide chain	Adenohypophysis (especially cattle, sheep); urine (in small amounts)	↑ crop sac wt; crop gland proliferation (pigeon); ↑ milk secretion (rabbit)	
6	Thyrotropic hormone[3]; TSH, thyrotropin	MW = 24,100-26,000; inactivated by boiling, cysteine, ketene, trypsin, pepsin, and chymotrypsin; nondiffusible; one peptide chain	Probably adenohypophysis (basophilic cells)	Uptake of I^{131} by thyroid; ↓ thyroid iodine (chick); ↑ thyroid cell ht (chick); ↑ thyroid gland wt (guinea pig); ↑ swelling of thyroid slices	
	Neurohypophysis				
7	Oxytocin; oxytocic hormone, pitocin, postlobin-O, posterior-lobe principle	IEP = 7.7; not adsorbed on charcoal; destroyed by acid, trypsin, tyrosinase; s. water, concentrated acetic acid, methyl alcohol. Amino acid comp. (cattle, swine): Cys, Tyr, Isoleu, Glu(NH_2), Asp(NH_2), Cys, Pro, Leu, Gly(NH_2).	Neurohypophysis	Contraction, isolated uterus (guinea pig); ↑ milk ejection (rabbit); ↓ blood pressure (chicken)	

/1/ Values for man. Other values: simian, MW = 25,400, IEP = 5.5; cattle, MW = 45,000, IEP = 6.85; sheep, MW = lengthen. /3/ Evidence for two fractions--one to stimulate hypertrophy of acinar cells and colloid secretion from factor" that can be separated from TSH.

VERTEBRATES

Targets	Principal Effects	Effect of Deficiency (-) Excess (+)	Secretion Inhibited by (I) Stimulated by (S)	Reference	
(F)	(G)	(H)	(I)	(J)	
		Adenohypophysis			
Ovarian follicles; seminiferous tubules	↑ spermatogenesis and growth of seminiferous tubules, follicle development (no ova production or estrogen secretion unless LH present)	(-): obesity, atrophy or immaturity of gonads; no maturation of ova or sperm; ↓ libido and potency, hair; ↑ H_2O metabolism (+): growth of follicles (may be numerous); estrogen secretion (FSH + LH), enlargement of tubules	(I) circulating estrogens and possibly androgens (S) castration; menopause; low blood levels of estrogens or possibly androgens; hypothalamo-pituitary apparatus	3,7,21, 22,24-28,31	2
Bones, especially epiphyseal cartilage; fibroblasts, most tissues	↑ skeletal and soft-tissue growth, protein anabolism, fibroblastic activity; ↓ pancreatic insulin (↑ in rats), maintenance of muscle growth	(-): dwarfism and/or infantilism; delayed closure of epiphyses (+): gigantism and/or acromegaly; hypertrophy of viscera[3]	(I) estrogens or androgens (large doses)	3,7,21, 24-26, 28,31	3
Maturing graafian follicles and interstitial cells (ovaries); interstitial cells of Leydig (testes)	↑ follicle maturation (production but not maintenance of corpus luteum), estrogen secretion, androgen secretion from testes synergistic with FSH in stimulating estrogen and ovulation	(-): lack of ovulation and luteinization; little or no estrogen or androgen secretion; atrophy of interstitial tissue in ovary and testis (+): ovulation and luteinization of prepared follicles; hypertrophy of Leydig tissue; ↑ estrogen secretion (with FSH), androgen secretion	(I) high levels of ovarian and testicular hormones (S) intermediate levels of ovarian hormones; hypothalamo-pituitary apparatus	3,7,21, 22,24, 26-28, 31	4
Mammary glands; corpus luteum; crop sac (pigeon)	↑ milk secretion, progesterone secretion by developed corpus luteum, uterine nidation and decidua; ↑ crop gland growth and secretion (pigeon)	(-): lactation failure; deficient secretion of progesterone by corpus luteum (+): lactation initiation; maintenance of corpus luteum and progesterone secretion; release of estrogen and progesterone by luteal tissue; crop gland development (pigeon)	(I) or (S) effects of androgens, FSH, LH, and progesterone on target organs (S) by oxytocin, in turn (S) by suckling	3,7,21, 22,24, 26-28, 31	5
Glands of orbit (?); thyroid gland	↑ thyroid hormone synthesis and secretion, cell height of thyroid epithelium, thyroid size, serum protein-bound iodine; ↓ iodine and colloid content of thyroid; stimulates proliferation of connective tissue?	(-): myxedema; cretinism (some forms); ↓ basal metabolic rate (+): goiter; hyperthyroidism; exophthalmos[4]; ↑ basal metabolic rate	(I) ↑ circulating thyroxine (I) or (S) nervous system (S) ↓ circulating thyroxine	3,7,19, 21,22, 24,26, 28,31	6
		Neurohypophysis			
Uterine and other smooth muscles; mammary glands	↑ uterine muscle contraction (and other smooth muscles to a lesser degree); facilitates movement of sperm up fallopian tubes; initiates labor; may stimulate release of prolactin	(-): delayed uterine contraction (pre- or post-partum); ↓ milk flow (+): uterine contraction (especially if prepared by estrogen); ↑ milk flow	(S) suckling	3,7,22, 24,27, 28,31	7

48,000, IEP = 6.8; whale, MW = 39,900, IEP = 6.2. /3/ More characteristic of acromegaly, since long bones do not gland, and the other to accelerate uptake from blood and hormone synthesis. /4/ May be caused by "exophthalmos

continued

	Name; Synonyms; Chemical Formula; (Systemic Name)	Properties	Sources	Assay Methods	Metabolites
	(A)	(B)	(C)	(D)	(E)
		Neurohypophysis			
8	Vasopressin; vasopressor principle, postlobin-V, vasopressor-antidiuretic principle, ADH	IEP = 10.8; adsorbed on charcoal; inactivated by trypsin, not pepsin; solubility same as for oxytocin. Amino acid comp. (human): Cys, Tyr, Phe, Glu(NH_2), Asp(NH_2), Cys, Pro, Arg, Gly(NH_2).	Neurohypophysis	↑ blood pressure (dog, rat); antidiuretic activity (dog, rat, excreting 5 ml urine/min)	ADH-like material
		Pars Intermedia			
9	Melanocyte-stimulating hormones; MSH, melanotropins, intermedin, melanophore hormone, chromatophorotropic hormone	IEP = 4.1; dialyzable; moderately heat stable; destroyed by trypsin; stable acid, alkali; s. water; i. ether, acetone	Intermediate lobe (many species, including mammals); anterior lobe (birds porpoises); chemical synthesis	In vitro: Intensity of darkening of isolated section of skin at end of 60 min *(Rana pipiens)*. Changes in reflectance correlate with amount of MSH in solution.	
	α-MSH[5]	Polypeptide consisting of 13 amino acid residues; IEP = 10.5-11; same residues and sequence occur in ACTH			
	β-MSH[6]	18 amino acid residues; 6 are same in kind and sequence as in α-MSH; acidic; IEP = approx. 4.1. Some interspecies differences. Both α- and β-MSH dialyzable, moderately heat stable, destroyed by trypsin; heating 10 min at 100° with 0.1 *N* NaOH racemizes MSH, resulting in potentiation and prolongation of darkening effect, dilution of acid; s. water; i. ether, acetone.			
		Pineal Body			
10	Adrenoglomerulotropin; GTH; (1-methyl-6-methoxy-1, 2, 3, 4-tetrahydro-2-carboline ?)	s. alcohol, $CHCl_3$, hexane; lipoid; nonpolar; pale tan with Le Rosen reagent	Pineal body or adjacent tissues	Stimulation of aldosterone secretion (in pinealectomized, partially decerebrate dog)	Unknown
11	Melatonin; $C_{13}H_{16}O_2N_2$; (*N*-acetyl-5-methoxytryptamine)	MW = 222; max. absorption 2,780°; s. aqueous, organic solvents; blue color with Ehrlich reagent	Pineal body (mammals); isolated from pineals (man, cattle, monkey); smaller amounts in central and peripheral nerves; in vivo precursor is serotonin	Degree of lightening of isolated sections of skin of amphibians *(Rana pipiens)*	5-Methoxytryptamine and 5-methoxyindoleacetic acid isolated from pineal tissue; 6-hydroxymelatonin isolated from urine (man, rat)
		Thyroid			
12	Thyroglobulin	MW = 680,000; amino acid comp.: His, Lys, *p*-Aminotryp, Tryp, Tyr, Diiodotyr, Thyrox, Cys, Meth, Ala, Glyc, Leu, Val, Ser, Monoiodotyr, Iodothyrox	Thyroid gland (follicles)	Limb bud growth (amphibian larva); growth (thyroidectomized rat); ↑ basal metabolic rate (thyroid-deficient subjects); ↑ O_2 consumption; oxidation of succinate; prevention of goiter; survival in anoxia (rat)	Same as thyroxine and proteins; released from gland by proteases and hyaluronidase

/5/ Amino acid composition: Ac-Ser, Tyr, Ser, Met, Glu, His, Phe, Arg, Try, Gly, Lys, Pro, Val (NH_2). /6/ Amino Lys, Asp.

VERTEBRATES

Targets (F)	Principal Effects (G)	Effect of Deficiency (-) Excess (+) (H)	Secretion Inhibited by (I) Stimulated by (S) (I)	Reference (J)	
		Neurohypophysis			
Capillaries; arterioles; coronary vessels; kidney vascular bed and tubules; smooth muscles	↓ kidney excretion of H_2O; ↑ NaCl and urea excretion, blood pressure (constriction of capillaries); promotes renal tubular water reabsorption	(-): diabetes insipidus, diuresis; ↓ NaCl and urea excretion (+): smooth muscle contraction; ↑ H_2O retention, blood pressure	(I) ↓ plasma osmotic concentration; ↑ extracellular volume (S) ↑ plasma osmotic concentration; ↓ extracellular volume	3,7,22, 24,27, 28	8
		Pars Intermedia			
Chromatophore cells in skin of lower vertebrates (reptiles, amphibians, fishes); adipokinetic effect may involve liver	Rapidly (within a few min) expands chromatophores, causing pigment granules to disperse and color skin (either in vivo or in vitro). Not species-specific; MSH from animals expands melanocytes in human skin; increases during most of pregnancy. In anuran larvae, MSH causes expansion of chromatophores and contraction of guanophores. Also has adipokinetic effect.	(-): chromatophore contraction and guanophore expansion; complete lack causes permanent blanching of skin (+): hyperglycemia; darkening of skin; potentiated or supplemented by ACTH	(I) corticoids (?); may be a feedback mechanism (S) central nervous system; ACTH ?	3,17,18	9
		Pineal Body			
Zona glomerulosa of adrenal cortex	Stimulates secretion of aldosterone, possibly from ACTH-dependent precursors along a branch in synthetic chain	(-): ↓ aldosterone secretion, resulting in loss of Na^+ from body (+): ↑ aldosterone secretion	Unknown	3,8,9	10
Melanocytes in skin; gonads	Blanches skin of amphibians and fishes (very potent); antagonistic to MSH; ↓ ovulation, estrus (rat); ↓ pineal wt and uptake of H^3-melatonin on exposure to light (rat); ↑ estrus	(-): darkening of skin of animals with expandable melanocytes; ↑ gametogenesis, estrus, ovarian wt; precocious puberty (+): blanching of skin; delay or decrease in estrus, gametogenesis; ↓ ovarian wt; erythema or punched-out ulcer (man)	(I) light; level of circulating melatonin ? (S) dark (?); ↓ concentration of circulating melatonin	3,16,32	11
		Thyroid			
None as such	Storage form of hormone in thyroid follicles	(-): delayed maturation, epiphyseal closure, and growth; incomplete differentiation or metamorphosis; cretinism; dwarfism; goiter (usually nontoxic or hyperiodic); slows reflexes; ↓ mentality, circulation, cardiac output, respiration, internal absorption (+): acceleration of growth, metabolic rate, maturation or metamorphosis; toxic goiter; uncouples oxidation from phosphorylation; mitochondrial swelling; thyrotoxicosis	(I) antithyroid drugs (thiouracil, thiourea, thiocyanate); thyroxine; high intake of I_2 or I^-; severe stress (first 24-48 hr) (S) thyrotropic hormone; chronic stress	4,23, 28,31	12

acid composition: Asp, Glu (swine); Ser (ox); Gly, Pro, Tyr, Lys, Met, Glu, His, Phe, Arg, Try, Gly, Ser, Pro, Pro,

continued

	Name; Synonyms; Chemical Formula; (Systemic Name)	Properties	Sources	Assay Methods	Metabolites
	(A)	(B)	(C)	(D)	(E)
			Thyroid		
13	Thyroxine; "T4"; $C_{15}H_{11}O_4NI_4$; (β-[(3,5-diiodo-4-OH-phenoxy)-3,5-diiodophenyl]-alanine)	MW = 777; needles; MP = 232-233; $[\alpha]_D$ = -3.2° (NaOH); s. alkali water, alkali or acid alcohol; i. water, alcohol, volatile solvents	Thyroid gland; plasma; synthesized from *p*-methoxyphenol and 3,4,5-triiodinitrobenzene	Limb bud growth (amphibian larva); growth (thyroidectomized rat); ↑ basal metabolic rate (thyroid-deficient subjects); ↑ O_2 consumption; oxidation of succinate; prevention of goiter; survival in anoxia (rat)	Deaminated and decarboxylated to tetraiodothyroacetic acid; as glucuronides or sulfates in urine, bile, or feces; deiodinated to T_3 or T_2
14	3,5,3'-Triiodothyrenine; "T3"; $C_{15}H_{12}O_4NI_3$	MW = 651; MP = 233; $[\alpha]_D^{29.5°}$ = +21.5° in 4.75% solution; s. HCl, alkaline water	Thyroid gland; plasma; deiodination of thyroxine	Methods similar to those for thyroxine; more active in most tests; same total calorigenic effect	
			Parathyroid		
15	Parathyroid hormone; parathormone, PTH	Max. MW = 8,500; 83 amino acid residues; stable dilute acid; s. water, saline, aqueous alcohol, 94% acetic acid, concentrated phenol, 50% glycerol; i. volatile organic solvents; inactivated by proteases, alkali; reversibly inactivated by mild oxidation	Parathyroids	Rate and degree of rise in serum Ca^{++} and decrease in serum phosphate (dog); Ca-mobilizing activity 2,000-3,000 USP units/mg; prevention of fall in plasma Ca in parathyroidectomized rat	
			Adrenal Cortex		
16	Aldosterone[7]; $C_{21}H_{28}O_5$; (11β 21-dihydroxy-3, 20-dioxopregn-4-en-18-al)	MW = 360; MP = 164; $[\alpha]_D$ = +160° (chloroform); s. organic solvents; sl. s. water. Urine concentration of aldosterone by double isotope derivative.	Zona glomerulosa of cortex (man, cattle, dog, frog, monkey, swine); precursors probably corticosterone, progesterone	Urinary Na/K ratio (adrenalectomized rat); muscle fatigue recovery (Everse and De Fremery test in adrenalectomized rat); muscular work performance (Ingle's test in adrenalectomized rat); deposition of liver glycogen (mouse, rat); wt maintenance (adrenalectomized dog); survival and growth (Kuizenga test in young, adrenalectomized rat); convulsion prevention (anti-insulin test in mouse); protection against cold (adrenalectomized rat); ↓ circulating eosinophils, circulating lymphocytes, thymus wt; chemical methods (formaldehydrogenic, reducing properties, reaction with phenylhydrazine)	Synthesized in vivo from corticosterone and progesterone; approx. 400 μg/da "turned over" in liver; mean 24 hr secretion (adult man) = 100 μg reduced in liver to tetrahydro derivative (inactive); mean excretion (man) = 10 μg/da, 30-40% as glucuronide, and 4-8% as free steroid; balance as other conjugates
17	Deoxycorticosterone[7]; DOC, DOCA; $C_{21}H_{30}O_3$; (Δ^4-pregnen-21-ol-3,-20-dione)	MW = 330; MP = 141-142; $[\alpha]_D$ = +178° (alcohol); s. acetone, benzene, chloroform, volatile solvents, vegetable oils; i. water	Adrenal cortex; synthesized commercially from cholesterol, diosgenin		Corticosterone; aldosterone; dehydrocorticosterone; pregnanediol; 17-ketosteroids
18	Corticosterone[8]; $C_{21}H_{30}O_3$; (11β, 21-dihydroxy-4-pregnene-3, 20-dione)	MW = 346; MP = 180-182; $[\alpha]_D$ = +262° (alcohol); s. organic solvents; sl. s. vegetable oils; v. sl. s. water	Adrenal cortex; blood; urine; synthesized in vitro from deoxycholic acid, pregnenolone, progesterone, cholesterol		Aldosterone; 11-dehydrocorticosterone; 17-ketosteroids (11-OH-androsterone and 11-keto-etio-cholane-3-[α]-ol-17-one)
19	Dehydrocorticosterone[8]; cortexone; $C_{21}H_{28}O_4$; (Δ^4-pregnen-21-ol-3,11,20-trione)	MW = 344; MP = 178-180; $[\alpha]_D$ = +258° (alcohol); s. organic solvents; i. water	Adrenal cortex; synthesized from deoxycholic acid		Similar to those of corticosterone; 11-ketopregnanediol main metabolite

/7/ Mineralocorticoid. /8/ Glucocorticoid.

VERTEBRATES

Targets	Principal Effects	Effect of Deficiency (-) Excess (+)	Secretion Inhibited by (I) Stimulated by (S)	Reference	
(F)	(G)	(H)	(I)	(J)	
		Thyroid			
All body cells; adenohypophysis	Regulation of rate of CHO, fat, protein, H_2O, mineral metabolism; stimulates growth, maturation, neuromuscular function, skin development, hematopoiesis, spermato- and oo-genesis, lactation, absorption through intestinal wall; regulation of TSH secretion; ↑ O_2 uptake of all organs and tissues	(-): delayed maturation, epiphyseal closure, and growth; incomplete differentiation or metamorphosis; cretinism; dwarfism; goiter (usually nontoxic or hyperiodic); slows reflexes; ↓ mentality, circulation, cardiac output, respiration, internal absorption (+): acceleration of growth, metabolic rate, maturation or metamorphosis; toxic goiter; uncouples oxidation from phosphorylation; mitochondrial swelling; thyrotoxicosis	(I) antithyroid drugs (thiouracil, thiourea, thiocyanate); thyroxine; high intake of I_2 or I^-; severe stress (first 24-48 hr) (S) thyrotropic hormone; chronic stress	4,7,15, 19,22-24,26-28,31, 34	13
	Same as thyroxine; more potent in goiter prevention, calorigenic activity, regulation of growth and metabolism			4,23, 27,28, 31	14
		Parathyroid			
Bones; kidneys, other soft tissues ?	↑ renal tubular absorption of Ca, distal renal tubular excretion of PO_4. Controls Ca and PO_4 level in blood via mineral exchange between blood and bones, and PO_4 excreted by kidneys.	(-): hypocalcemia; irritability of nervous system; convulsive seizures; tetany; phosphate retention (+): hypercalcemia, renal calculi; ↑ calcium and phosphate excretion, osteoclastic activity; ↓ growth	(I) high serum (Ca^{++}) (S) low serum (Ca^{++}); high serum (PO_4)	5,7,21, 22,24, 26-28	15
		Adrenal Cortex			
Distal renal tubule	Promotes renal excretion of K, and retention of Na and Cl; indirectly promotes reabsorption of H_2O in distal tubules; 25-100 times more potent than deoxycorticosterone	(-): ↓ Na^+, H_2O in blood and muscles; hemoconcentration; loss of Na through kidneys (+): reverse of above; hypertension; congestive heart failure	(I) ↓ K^+ concentration in blood, secretion of adrenoglomerulotropin; ↑ Na^+, hemodilution (S) glomerulotropin; ACTH; ↑ K^+, blood pressure in carotid arteries; ↓ Na^+, dehydration of blood	6,10 21,22, 24,27	16
Distal renal tubule	Similar to aldosterone; chiefly of historical interest; normally secreted only in trace amounts	(+): acute Na^+ retention and K^+ loss; hypertension; polyuria; ↑ plasma volume and edema	Unknown	6,7,10, 13,15, 21,22, 24,26-28	17
Muscles, liver, capillaries, kidneys, pancreas (?), integument, lymphoid organs and bone marrow, circulating blood cells	Effects of glucocorticoids are qualitatively comparable, but differ quantitatively for glycogen deposition in liver, muscle work performance, hypersensitivity reactions, thymus involution, gluconeogenesis, maintenance of renal function, K/Na ratio and H_2O balance, muscular fatigue recovery, cold protection, CHO metabolism,	(-): asthenia; hemoconcentration; skin pigmentation; ↓ wt, blood glucose, liver glycogen, stress resistance, blood pressure, secondary sex characteristics, growth in young; ↑ K/Na ratio in serum. Slowing of electrical discharges in nerves reversed by hydrocortisone. (+): reverse of above; Cushing's syndrome; hirsutism; negative	(S) ACTH (α-corticotropin)	6,7,10, 15,20-22,24, 26-28, 33	18
				6,7,10, 13,21, 22,24, 26-28, 33	19

continued

	Name; Synonyms; Chemical Formula; (Systemic Name)	Properties	Sources	Assay Methods	Metabolites
	(A)	(B)	(C)	(D)	(E)
	Adrenal Cortex				
20	Hydrocortisone[a]; 17-hydroxycorticosterone, cortisol; $C_{21}H_{30}O_5$; (Δ^4-pregnene-11β, 17α, 21-triol-3, 20-dione)	MW = 362; MP = 217-220; $[\alpha]_D$ = +167° (alcohol); s. chloroform, ether, vegetable oils; sl. s. water	Adrenal cortex; synthesized from deoxycholic acid	Same as for aldosterone; Porter-Silber reaction; *m*-dinitrobenzene reaction	Tetrahydrocortisol; cortisone
21	Cortisone[a]; 17-OH-11-dehydrocorticosterone; $C_{21}H_{28}O_5$; (Δ^4-pregnene-17α, 21-diol-3, 11, 20-trione)	MW = 360; MP = 220-224; $[\alpha]_D$ = +209° (alcohol); s. acetone, chloroform, benzene, ether, vegetable oils; sl. s. water	Adrenal cortex; placenta; synthesized in vitro from squalene, cholesterol, pregnenolone, progesterone	Same as for aldosterone; Porter-Silber reaction	Tetrahydrocortisone; β-cortolone
22	Fluorocortisone; $C_{21}H_{29}O_5F$; (9α-fluoro-17β-[1-keto-2-hydroxyethyl]-Δ^4-androstene-3,-11-dione-17α-ol)	MW = 380; MP = 233-234 (acetate); $[\alpha]_D^{23°}$ = +123° (acetate)	Synthetic	Same as for aldosterone	
	Adrenal Medulla				
23	Epinephrine; adrenaline, suprarenine, adrenine	MW = 183; MP (L) = 207-211; $[\alpha]_D$ = -50° to -53.5°; s. alkali, acid; sl. s. water; v. sl. s. alcohol; i. ether, chloroform	Adrenal medulla; synthesized (commercially) from catechol, (in vivo) tyrosine; methylation of norepinephrine	Isolated heart stimulation (frog); uterus relaxation (cat); pupil dilation (cat); ↓ peristalsis (rabbit); ↑ blood pressure (cat)	Catechol derivatives; 50% to metanephrine (5-methoxyepinephrine), 30% to 3-methoxy-4-hydroxymandelic acid (VMA) in urine
24	Norepinephrine; arterenol, noradrenaline	MW = 169; MP (L-bitartrate) = 163-164, (L-HCl) = 146-147; solubility same as for epinephrine	Adrenal medulla; various nerves, especially splenic; spleen; heart; blood vessels	Same as for epinephrine in all tests except pressor and contraction of gravid uterus	Methylated to epinephrine by adrenals in presence of ATP; conjugated normetanephrine and VMA in urine
	Ovaries				
25	Equilenin; $C_{18}H_{18}O_2$; ($\Delta^{1,3,5:10,6,8}$-estrapentaen-3-ol-17-one)	MW = 266; MP = 258-259; $[\alpha]_D$ = +89° (dioxane); s. volatile solvents; sl. s. alcohol, vegetable oils; i. water	Synthesized; 4 stereoisomers; natural estrogen from urine (pregnant mare)	Phenolsulfonic acid (Kober); $ZnCl_2$/benzoyl Cl, sulfanilic acid/$NaNO_2$ (Pincus); spectrophotometric; estrus changes in vagina (immature mouse, rat) (Allen-Doisy)	One inactive stereoisomer is produced by catalytic dehydrogenation of estrone
26	Equilin; $C_{18}H_{20}O_2$; ($\Delta^{1,3,5:10,7}$-estratetraen-3-ol-17-one)	MW = 268; MP = 238-240; $[\alpha]_D$ = +308° (dioxane); s. volatile solvents; sl. s. vegetable oils; i. water	Urine (pregnant mare)		Easily dehydrogenated to equilenin
27	Estradiol-17β; dihydrotheelin, dihydrofolliculin, dihydroestrone, di-OH-estrin; $C_{18}H_{24}O_2$; (3,-17β-di-OH-1, 3,-5:10 estratriene)	MW = 272; MP = 178; $[\alpha]_D$ = +82° (dioxane); s. alkali, volatile solvents; sl. s. vegetable oils; i. water	Urine (pregnant woman, mare, rabbit); ovary (swine); testes (stallion); human placenta; synthesized from cholesterol. Estradiol-17α from urine (pregnant cattle, goat)	*See* equilenin. Estimation of dehydrogenases in placenta.	Estradiol-17α converted to estrone, but not estradiol-17β, in calves

/a/ Glucocorticoid.

VERTEBRATES

Targets (F)	Principal Effects (G)	Effect of Deficiency (-) Excess (+) (H)	Secretion Inhibited by (I) Stimulated by (S) (I)	Reference (J)	
		Adrenal Cortex			
Chiefly muscle, liver, connective tissue; also capillaries, kidneys, pancreas (?), integument, lymphoid organs and bone marrow, circulating blood cells	collagen maintenance, normal capillary permeability, protection against stress and shock. Corticosterone is of minor importance, but has weak antianabolic and catabolic effects. Hydrocortisone and cortisone principal glucocorticoids (man); stimulate gluconeogenesis and redistribution of fat; lymphocytopenia. *(See* preceding page)	N balance; hyperglycemia; osteoporosis; obesity; muscle wasting; diabetes; alkalosis; inhibition of inflammatory responses and wound healing; diuresis; supression of antibody formation; hyperglycemia (hydrocortisone); ↑ gastric acidity (hydrocortisone) *(See* preceding page)	(S) ACTH (α-corticotropin)	1,6,7, 10,13, 21,22, 24,26-28,33	20
				1,6,7, 10,13, 21,22, 24,26-28,33	21
Joints affected with rheumatoid arthritis				2,11, 12,29	22
		Adrenal Medulla			
Sympathetic nervous system; heart muscle; smooth and skeletal muscle; liver phosphorylase; adenohypophysis; lipase	Relaxation of nongravid uterus, peripheral arterioles, bronchial muscles; ↑ contraction of heart muscle (↑ output and rate), gravid uterus, iris muscle (radial), capillaries; ↑ spleen size, glucogenolysis, blood coagulation, ACTH secretion, salivary and sweat gland secretions; ↓ peristalsis; moderate lipolysis. Epinephrine: slight pressor effect; moderately increased cardiac output; great excitation of central nervous system; eosinopenia; hyperglycemia; greatly ↑ basal metabolic rate. Norepinephrine: great pressor effect; slight or no ↑ cardiac output; no excitation of central nervous system; slight eosinopenia and hyperglycemia; moderately ↑ basal metabolic rate.	(-): no clinical syndrome (+): over-secretion rare; may cause paroxistic hypertension and, in some instances, sustained hypertension. Norepinephrine: pheochromocytoma.	(S) sympathetic nervous system, via splanchnic nerve; stress	6,7,15, 20,22, 24,26-28,30	23
Similar to epinephrine but causes arteriolar constriction; tends to decrease cardiac output; pressor effect is not reversed by ergotoxine				6,7,22, 24,27	24
		Ovaries			
All female sex organs; mammary glands; mucous membranes; adenohypophysis	Estrogenic. Endometrial proliferation; development and maintenance of vaginal mucosa, cornification of superficial layer; antagonizes androgen effects; ↑ mammary gland duct development, uterine motility, growth of axillary and pubic hair (♀, human), growth of down (♀, bird), growth of all female secondary sex organs. β-Estradiol stimulates *trans*dehydrogenases in human placenta, slows growth of skeleton, promotes closure of epiphysis; moderately stimulates protein anabolism and calcification of bones.	Unknown		3,10, 15,21, 24,26, 27	25
		Unknown		3,15, 21,24, 26,27	26
All female sex organs; mammary glands; mucous membranes; adenohypophysis; osteoblasts		(-): immaturity or atrophy of accessory sex organs; lack of secondary sex characteristics and female behavior patterns; ↓ mammary gland development; delayed epiphyseal closure; long bones continue to grow; osteoporosis (+): precocious maturity; hypertrophy of accessory sex organs and mammary glands; estrus changes; cystic	(I) high blood levels of estrogens ? (S) LH, combined FSH and LH	3,7,10, 15,21, 22,24, 26-28, 31,33	27

continued

	Name; Synonyms; Chemical Formula; (Systemic Name)	Properties	Sources	Assay Methods	Metabolites
	(A)	(B)	(C)	(D)	(E)
	Ovaries				
28	Estriol; theelol, tri-OH-estrin; $C_{18}H_{24}O_3$; ($\Delta^{1,3,5:10}$-estratriene-3, 16α, 17β-triol)	MW = 288; MP = 282; $[\alpha]_D$ = +53 to +63° (dioxane); s. volatile solvents, alkali; sl. s. vegetable oils; i. water	Urine (pregnant woman); human placenta; synthesized from estrone, β-estradiol	*See* equilenin	β-Estradiol; 4-pregnene-20β-ol-3-one $\updownarrow$ estrone; 4-pregnene-20α-ol-3-one $\updownarrow$ α-estradiol $\downarrow$ (from estrone) estriol (principal metabolite in urine; excreted as water-soluble inactive glucuronide)
29	Estrone; theelin, folliculin, keto-OH-estrin; $C_{18}H_{24}O_2$; ($\Delta^{1,3,5:10}$-estratrien-3-ol-17-one)	MW = 270; MP = 255; $[\alpha]_D$ = +170° (dioxane); s. volatile solvents, alkali; v. sl. s. water; sl. s. vegetable oils	Adrenal cortex; urine (man, bull, steer); synthesized from cholesterol, diosgenin	*See* equilenin	
30	Progesterone; progestin, luteosterone; $C_{21}H_{30}O_2$; (Δ^4-pregnene-3,-20-dione)	MW = 314; MP (α) = 128, (β) = 121; $[\alpha]_D$ = +172 to +182° (dioxane); s. volatile solvents; sl. s. vegetable oils; i. water	Corpus luteum; placenta; adrenal cortex; synthesized from cholesterol or stigmasterol	*See* equilenin	Pregnanediol; 17α-hydroxyprogesterone
31	Relaxin; releasin	Polypeptide; IEP = 5.5; s. water and 95% alcohol	Serum (pregnant woman, cat, dog, mare, rabbit, sow); placenta; corpus luteum; ovaries; endometrium	Degree of relaxation of pelvic ligaments (guinea pig)	Unknown
	Placenta[9]				
32	Chorionic gonadotropin; HCG, prolan	MW = 30,000; IEP = 2.95; $[\alpha]_D^{20°}$ = -68°; s. water, 50% acetone, 60% alcohol; 12,000 I.U./mg	Placenta, blood, urine (pregnant female); peak in 60-75 days after first day of last menses	Corpus luteum formation (mouse); ovarian wt (rat); ovulation (rabbit); ovarian cell repair (immature, hypophysectomized rat)	Human chorionic gonadotropin excretic basis of Aschheim-Zondek pregnancy test
	Testes				
33	Testosterone; $C_{19}H_{28}O_2$; (Δ^4-androsten-17β-ol-3-one)	MW = 288; MP = 155-156; $[\alpha]_D$ = +109° (alcohol); absorption maximum = 238 mμ; s. alcohol, ether, volatile solvents; sl. s. vegetable oils; i. water	Testes (man, bear, bull, rat, stallion); synthesized from cholesterol, acetate, and dehydroandrosterone	Alkali *m*-dinitrobenzene; $SbCl_3$-acetic anhydride (colorimetric); chromatography; comb growth (capon); blackening of bill (sparrow); ↑ wt of seminal vesicle, prostate (castrated rat). Testosterone: Girard's reagent T, followed by polarography.	Androsterone; etiocholanolone; epiandrosterone; estradiol; estrone (urine)
34	Dehydroepiandrosterone; dehydroisoandrosterone; $C_{19}H_{28}O_2$; (Δ^5-androsten-3β-ol-17-one)	MW = 288; MP (leaflets) = 152-153; $[\alpha]_D$ = +10.9° (alcohol); s. alcohol, ether, benzene; precipitated by digitonin; i. water	Urine (man, bull, pregnant cow); testes (bull); synthesized from cholesterol		May be intermediate in synthesis of androgens from acetate or pregnenalone; metabolized to androstenedione
35	Androsterone; $C_{19}H_{30}O_2$; (androstan-3-[α]-ol-17-one)	MW = 290; MP = 185.5; $[\alpha]_D$ = +87.8° (dioxane); s. volatile solvents; sl. s. vegetable oils; not precipitated by digitonin; i. water	Urine (man, bull, pregnant cow); synthesized from cholesterol or sitosterol		Dehydroepiandrosterone, Δ^4-androstene-3, 17-dione, 17-hydroxyprogesterone. Found only in urine (probably a metabolite of testosterone).

/9/ Placenta also produces estrogens and progesterone.

VERTEBRATES

Targets	Principal Effects	Effect of Deficiency (-) Excess (+)	Secretion Inhibited by (I) Stimulated by (S)	Reference	
(F)	(G)	(H)	(I)	(J)	
Ovaries					
All female sex organs; mammary glands; mucous membranes; adenohypophysis; osteoblasts	*See* entry 25	hyperplasia of endometrium; blocking of ovulation; skeletal growth deceleration (premature closing of epiphyses); excessive calcification of tissues, if parathyroids are normal *(See* preceding page)	(I) high blood levels of estrogens ? (S) LH, combined FSH and LH	3,7,10, 15,21, 22,24, 26-28, 31,33	28
				3,7,10, 15,21, 22,24, 26-28, 31,33	29
Endometrium of uterus; mammary gland lobules and alveoli; kidney tubules; adenohypophysis	Luteinizing. Preparation of endometrium for implantation of zygote; ↓ uterine contractions; ↑ mammary gland development, metabolism and excretion of estrogens; stimulation of protein catabolism and galactose oxidation	(-): lack of normal cyclic changes and of endometrial development for implantation and gestation (+): pregestational changes; pregnancy prolongation; inhibition of uterine growth, especially of endometrium; ↑ Na and K excretion, catabolism	(S) LTH	3,7,10, 15,21, 22,24, 26-28, 31,33, 34	30
Pubic ligaments	Relaxation of pubic ligament by replacing bone with connective tissue; synergistically with other hormones promotes mammary development and softening of cervix	Not definitely known	(S) estrogens ?	3,7,22, 24,31, 33	31
Placenta[9]					
Ovaries, especially corpus luteum	Corpus luteum maintenance in pregnancy; in nonpregnant women, stimulates ovulation. Human chorionic gonadotropin → luteinizing corpus luteum; pregnant mare serum → luteinization, follicle development.	(-): abortion (+): toxemias of pregnancy ?	(I) sex steroids	7,20, 22,26-28,31	32
Testes					
All male sex organs; adenohypophysis; muscle; hair follicles; epiphyses of long bones; vocal cords	Androgenic. ↑ development of male secondary sex organs and sex characteristics, libido, folliculoid and luteoid activity (immature female), basal metabolic rate and protein anabolism; positive balances of N, Ca, K, P; ↓ creatinuria and amino acid catabolism.	(-): immaturity or atrophy of accessory sex organs; lack of secondary sex characteristics and male behavior patterns; poor muscle development and function; delayed closure of epiphyses; ↓ excretion of 17-ketosteroids in urine (+): precocious sex development; hypertrophy of accessory sex organs; ↑ skeletal growth until closure of epiphyses, muscle mass, hirsutism, excretion of 17-ketosteroids in urine; ↓ scalp hair ?	(I) androgens (S) FSH + ICSH	3,10, 15,21, 22,24, 26-28, 31,33	33
				3,10, 15,21, 22,24, 26,27, 31,33	34
				3,7,10, 15,21, 22,24, 26-28, 31,33	35

continued

	Name; Synonyms; Chemical Formula; (Systemic Name) (A)	Properties (B)	Sources (C)	Assay Methods (D)	Metabolites (E)
	Pancreas				
36	Insulin protein (polypeptide)[10]	MW = 36,000; monomer composed of two polypeptide chains; destroyed by oxidizing or reducing agents. MP = 223; IEP = 5.3; s. water, alcohol; precipitated by protein precipitants; stable acid; destroyed by alkali.	β-cells of islets of Langerhans (various species)	Convulsions (mouse); hypoglycemia (starved rabbit); glucose uptake by diaphragm (rat, mouse); metabolism of glucose-1-C^{14} by fat pad (rat); rate of displacement of beef insulin-I^{131} by human insulin (immunized guinea pig); ↓ blood glucose (adrenodemedullated, hypophysectomized, diabetic rat)	
37	Glucagon (polypeptide)[10]	MW = 3,485; 29 amino acid residues; two polypeptide chains of different lengths; IEP = 7.5-8.5; s. dilute alkali and acid; i. water; stable alkali	α-cells of islets of Langerhans	Rise of blood glucose level at intervals of 20, 30, 45, 60, 90, and 120 min after intravenous injection; rate of glycogenolysis in liver	Not known
	Gastrointestinal Tract				
38	Cholecystokinin; CCK	MW = 5,000-10,000 (?); IEP = 5.0-5.5; dialyzable; s. water	Upper intestinal mucosa	Contraction of gallbladder (dog)	Metabolized as protein ?
39	Enterocrinin	s. acid, water, alcohol; i. ether, acetone; salted out by NaCl	Intestinal mucosa (man, cat, cow, dog, hog)	↑ flow of intestinal juice in jejunum (dog)	Metabolized as protein ?
40	Enterogastrone	s. water; i. organic solvents; dialyzable; destroyed by pepsin	Duodenal mucosa	↓ stimulating effect of exogenous histamine on HCl secretion	Urogastrone ?
41	Gastrin	IEP = 8; heat stable; destroyed by ultraviolet, alkali, pepsin; dialyzable	Gastric mucosa, especially pylorus	No standard assay method	Unknown
42	Pancreozymin	Salted out by NaCl; s. absolute alcohol, water	Upper intestinal mucosa	Increase in enzymes in pancreatic juice	Unknown
43	Secretin	MP = 234; salted out by NaCl, CCl_3COOH; s. dilute acidic water	Upper intestinal mucosa	Volume of pancreatic juice (dog)	Unknown
44	Urogastrone	Same as for enterogastrone	Urine	Same as for enterogastrone	Unknown
	Nervous System				
45	Acetylcholine; ACh	MW = 163; MP (Br) = 143; quaternary salt unstable; s. water, alcohol, ether, oils; i. ether; salts v. s. water	Ganglia of parasympathetic nervous system; brain; synthesized commercially	None	

/10/ Data are for cattle.

Contributors: (a) Pritham, Gordon H., (b) Russell, Jane A.

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Targets	Principal Effects	Effect of Deficiency (-) Excess (+)	Secretion Inhibited by (I) Stimulated by (S)	Reference	
(F)	(G)	(H)	(I)	(J)	
		Pancreas			
All tissues involved in carbohydrate metabolism; hexokinases in mitochondria	Regulates CHO and fatty acid metabolism; stimulates hexokinases, phosphorylases; promotes uptake of glucose by cells; oxidation of CHO; stimulates lipogenesis, transport and oxidation of lipids; stimulates amino acid transport into cells and protein synthesis; stimulates synthesis of mucopolysaccharides. ↓ gluconeogenesis, ketogenesis.	(-): diabetes mellitus (hyperglycemia, glycosuria, ketonuria; ↓ wt and blood volume, negative nitrogen balance); delayed wound healing; gangrene; dwarfism; ↓ response to growth hormone; ↓ HPO_4 uptake by cells; ↓ ATP; ↓ glycogenesis, lipogenesis, proteogenesis (+): hyperinsulinism (hypoglycemia, convulsions, nausea, muscular weakness, anxiety, confusion); ↑ food intake, fat and protein deposition	(I) low blood glucose; antagonized by growth hormone, glucosteroids (corticoids), epinephrine, thyroxine, glucagon (S) vagus stimulation; ↑ blood glucose; ↑ growth hormone; ↑ ACTH, thyroxine, estrogens	7,15, 21,22, 24,26, 28	36
Similar to insulin	Antagonistic to insulin; raises blood glucose; promotes glycogenesis in liver but not muscle; inhibits synthesis of fatty acids from precursors; ↑ O_2 consumption by tissues, excretion of ions by kidney	(-): low blood glucose (+): high blood glucose; opposes action of insulin	(I) high blood glucose ? (S) low blood glucose ?	27,28, 30,31	37
		Gastrointestinal Tract			
Gallbladder	↑ contraction and emptying of gallbladder	?	(S) fat, protein, acid in duodenum	14,21, 28	38
Secretory cells of ileum, jejunum	↑ secretion of succus entericus, volume rate and enzyme concentration	?	(S) food in intestine	14,21	39
Stomach	↓ motor activity and acid secretion of stomach	?	(S) sugar, fat in intestine	14,21, 28	40
Parietal (HCl-producing) cells, stomach	↑ HCl secretion (but not pepsin) by gastric mucosa	?	(S) mechanical distention; protein degradation products	14,21, 28	41
Enzyme-secreting cells of pancreas	↑ enzyme secretion by pancreas (no effect on volume rate)	?	(S) peptones, amino acids, soaps, fats in duodenum	14,21	42
Pancreas (acinar or exocrine), liver	↑ volume rate of pancreatic enzymes (no effect on concentration), bile secretion	(-): hyposecretion of pancreatic enzymes and bile (+): excess doubtful	(S) HCl, protein degradation products, digested fat or bile in small intestine	14,21, 28	43
Gastric mucosa and muscularis	↓ HCl secretion, stomach muscle contractions	?		14,21, 28	44
		Nervous System			
Muscles, especially involuntary (ACh released at neuromuscular junctions, synapses)	Conduction of electrical impulses along nerve fibers; arteriolar dilation; effects (cholinergic) generally opposite to those of epinephrine; ↓ heart rate	?		15,22, 24,27, 28,30	45

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91. ENDOCRINE ORGANS AND HORMONES: INVERTEBRATES

	Phylum and Class (A)	Possible Endocrine Organs or Areas[1] (B)	Possible Endocrine Factors [Chemistry] (C)	Effects (D)
1	Chordata[2]	Some neurosecretion in brain		
2		Endostyle	Minimal thyroxinogenesis	?
3	Echinodermata	Some neurosecretion in circum-oral nerve-ring and radial nerves	[Polypeptide?]	Stimulation of spawning
4				Water balance
	Arthropoda			
5	Arachnida	Brain-and-neurohemal-organ neurosecretory system		
6	Crustacea	X-organ-and-sinus-gland neurosecretory system (in eyestalk)	Somatic chromatophorotropins [Protein-polypeptide?]: A substance (=PLH of F. Brown) UDH (*Uca*-darkening hormone)	Somatic pigmentation: Concentration of red pigments; Dispersion of melanins
7			Retinal chromatophorotropin(s)	Retinal pigment movements in light and dark adaptation
8			Molt-influencing hormones (MIH and MAH)	Probable inhibition or acceleration of Y-organ secretion
9			Gonad-inhibiting hormones (in all ♀ crustaceans and ♂ crabs)	
10			Metabolic factors?	O_2 consumption, Ca^{++} metabolism, water metabolism (probably related to molting); blood sugar regulation (diabetogenic)

/1/ Neurosecretion, as used in this column, refers to the presence of special secretory-appearing neurons, regardless of evidence for actual neurohormone production. /2/ Cephalochordata and Urochordata only.

continued

91. ENDOCRINE ORGANS AND HORMONES: INVERTEBRATES

	Phylum and Class	Possible Endocrine Organs or Areas[1]	Possible Endocrine Factors [Chemistry]	Effects
	(A)	(B)	(C)	(D)
	Arthropoda			
11	Crustacea	Brain(?)-and-postcommissure-organ neurosecretory system	Somatic chromatophorotropins [Protein-polypeptide?]: A substance A' substance B substance (=CDH of F. Brown)	Somatic pigmentation: Concentration of red pigments Concentration of white and some red and black pigments Dispersion of red pigments
12		Thoracic-ganglion-and-pericardial-organ neurosecretory system	[5-Hydroxytryptamine?; 5,6-dihydroxytryptamine?; polypeptide?]	Frequency and amplitude of heart beat
13		Thoracic-ganglion-and-anterior-ramifications neurosecretory system		Rate of gas transport?
14		Neurosecretion in brain and ventral ganglia unrelated to known neurohemal areas		
15		Y-organ	Molting hormone (insect ecdyson?)	Rate of molting in adult; under control of sinus gland MIH and MAH
16		Androgenic gland	Androgenic hormone	Male gonad, gonoduct, and secondary sex character development. Under control of sinus gland testis-inhibitory factor in crabs?
17		Ovary?		Female secondary sex characters
18	Insecta	Brain-and-corpus-cardiacum neurosecretory system	"Brain hormone" = ecdysiotropin [Protein? or steroid related to cholesterol?]	Stimulates secretion by ecdysial (molting) gland
19		Tritocerebral neurosecretion	Chromatophorotropin in phasmids and *Corethra* larva	
20		Neurosecretion in subesophageal ganglion		Activity regulation in cockroaches; release of chromatophorotropin in phasmids; egg diapause in *Bombyx*
21		Neurosecretion in ventral ganglia		
22		Corpus cardiacum (intrinsic function)	Myotropic factors	Motility of oviduct, gut, Malpighian tubules
23			Cardioaccelerator factor (produced by pericardial cells under corpus cardiacum stimulation?) [Orthodiphenol?]	Heart beat
24			Diabetogenic factor	Blood sugar regulation
25				Depression of spontaneous activity in nerve cords
26		Corpus allatum	Neotenin = "juvenile" hormone [Fat-soluble; related to farnesol ($C_{15}H_{25}OH$)?]	Larval and nymphal development; gonadotropic in some ♀ insects (not Lepidoptera or phasmids)
27		Corpora cardiaca and allata	Metabolic factors?	Water metabolism?
28		Ecdysial (molting) gland: ventral, prothoracic, thoracic, peritracheal, etc.	Ecdyson = growth and differentiation (GD) hormone = molting hormone [$C_{27}H_{44}O_6$ (polyhydroxysteroid)]	Larval and pupal molting (protein synthesis, quinone tanning in integument, tyrosine metabolism); differentiation of adult structures; diapause termination
29		Gonads	Sex hormones?	
30	Symphyla[3]	Brain-and-cerebral-gland neurosecretory system		Molt inhibition

/1/ Neurosecretion, as used in this column, refers to the presence of special secretory-appearing neurons, regardless of evidence for actual neurohormone production. /3/ Also Chilopoda, Diplopoda, and Pauropoda.

continued

91. ENDOCRINE ORGANS AND HORMONES: INVERTEBRATES

	Phylum and Class (A)	Possible Endocrine Organs or Areas[1] (B)	Possible Endocrine Factors [Chemistry] (C)	Effects (D)
	Arthropoda			
31	Onychophora	Neurosecretion in brain, ventral cord, pedal nerves; neurohemal infracerebral organs?		
	Annelida			
32	Hirudinea	Neurosecretion in brain and nerve cord; neurohemal organ at base or posterior surface of brain		Reproduction?
33	Oligochaeta	Same as in Hirudinea		Secondary sex characteristics; gamete maturation; regeneration; pigmentation
34	Polychaeta	Same as in Hirudinea	"Juvenile hormone"	Gonad inhibition; inhibition of heteronereid transformation
35				Regeneration
36	Echiuroidea	Neurosecretion in ventral cord		
37	Sipunculoidea	Neurosecretion in brain; anterior neurohemal area ("finger organs")		Reproduction? Myotropic factor?
	Mollusca			
38	Cephalopoda	Some neurosecretion in brain		
39		Optic glands	Inhibited by light through optic tracts	Stimulation of sexual maturation and gonad development
40	Bivalvia	Neurosecretion in most ganglia		Inhibition of spawning
41	Scaphopoda	Neurosecretion in various ganglia		
42	Gastropoda	Neurosecretion in all ganglia		Gonad development? Water balance.
43		Gonads		Reproductive tract development
44	Aschelminthes[4]	Neurosecretion in cephalic nerve ring		
45	Nemertina	Neurosecretion in brain		Gonad inhibition in female
46		Cerebral organ		Spawning?
47	Platyhelminthes	Neurosecretion in brain	[Water-soluble]	Regeneration
48	Cnidaria	Neurosecretion (diffuse?)		Growth stimulation and inhibition

/1/ Neurosecretion, as used in this column, refers to the presence of special secretory-appearing neurons, regardless of evidence for actual neurohormone production. /4/ Nematoda only.

Contributor: Bern, Howard A.

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92. RELATIVE ACTIVITY OF GROWTH REGULATORS: PLANTS

Part I. CELL ELONGATION OF OAT COLEOPTILES

Elongation effect was determined by floating 15 apical sections (3 mm in length) of decapitated *Avena* coleoptiles, 90-92 hours old, on the surface of 25 ml of solution in a covered Petri dish, at 24°C for 24 hours. Where concentrations greater than $10^{-5}\ M$ were required for an elongation of 0.15 mm, the pH of the solutions was adjusted to 5.6 with NaOH. Activity Index $= \dfrac{\text{molar concentration of indole-3-acetic acid inducing an elongation of 0.15 mm}}{\text{molar concentration of growth regulator inducing an elongation of 0.15 mm}} \times 100.$

	Compound	Activity Index
	(A)	(B)
	Indole acids	
1	3-Indoleacetic acid ($5 \times 10^{-8}\ M$)	100
2	Indole-3-acetonitrile	250
3	4-Chloroindole-3-acetic acid	140
4	4,7-Dichloro-2-methylindole-3-acetic acid	0.1
5	5,7-Dichloro-2-methylindole-3-acetic acid	1.5
6	5-Fluoroindole-3-acetic acid	50
7	6-Fluoroindole-3-acetic acid	100
8	5-Hydroxyindole-3-acetic acid	0.5
9	2-Methylindole-3-acetic acid	1.5
10	Indole-3-butyric acid	15
11	Indole-3-propionic acid	1.5
	Phenoxy acids	
12	Phenoxyacetic acid	0.03
13	2-Acetylphenoxyacetic acid	0
14	3-Acetylphenoxyacetic acid	0.02
15	4-Acetylphenoxyacetic acid	0
16	3-Aminophenoxyacetic acid	0.005
17	4-Aminophenoxyacetic acid	0.02
18	2-Bromophenoxyacetic acid	0.1
19	3-Bromophenoxyacetic acid	2.5
20	4-Bromophenoxyacetic acid	1.5
21	2,4-Dibromophenoxyacetic acid	12.5
22	2,6-Dibromophenoxyacetic acid	0
23	2,4,6-Tribromophenoxyacetic acid	0
24	3-Carboxyphenoxyacetic acid	0
25	4-Carboxyphenoxyacetic acid	0
26	2-Chlorophenoxyacetic acid	0.06
27	3-Chlorophenoxyacetic acid	2
28	4-Chlorophenoxyacetic acid	5
29	2,4-Dichlorophenoxyacetic acid	50
30	2,6-Dichlorophenoxyacetic acid	0
31	3,5-Dichlorophenoxyacetic acid	0
32	2,4,5-Trichlorophenoxyacetic acid	25
33	2,4,6-Trichlorophenoxyacetic acid	0
34	2,4-Dichloro-6-methylphenoxyacetic acid	0
35	2,4-Dichloro-5-nitrophenoxyacetic acid	0.2
36	3-Cyanophenoxyacetic acid	0.02
37	4-Cyanophenoxyacetic acid	0
38	2-Ethyl-4-chlorophenoxyacetic acid	0
39	2-Fluorophenoxyacetic acid	0
40	3-Fluorophenoxyacetic acid	0.02
41	4-Fluorophenoxyacetic acid	5
42	2,4-Difluorophenoxyacetic acid	2
43	2-Trifluoromethylphenoxyacetic acid	0
44	3-Trifluoromethylphenoxyacetic acid	7
45	3-Pentafluorosulfurphenoxyacetic acid	1
46	3-Hydroxyphenoxyacetic acid	0.07
47	4-Hydroxyphenoxyacetic acid	0.01
48	2-Iodophenoxyacetic acid	0.1
49	3-Iodophenoxyacetic acid	7
50	4-Iodophenoxyacetic acid	0
51	2,4-Diiodophenoxyacetic acid	0
52	2-Isopropylphenoxyacetic acid	0
53	2-Methoxyphenoxyacetic acid	0
54	3-Methoxyphenoxyacetic acid	0.1
55	4-Methoxyphenoxyacetic acid	0.03
56	2-Methylphenoxyacetic acid	0.2
57	3-Methylphenoxyacetic acid	0.07
58	4-Methylphenoxyacetic acid	0.05
	Phenoxy acids	
59	2,4-Dimethylphenoxyacetic acid	0.5
60	2,5-Dimethylphenoxyacetic acid	0.2
61	3,5-Dimethylphenoxyacetic acid	0
62	2,4,6-Trimethylphenoxyacetic acid	0
63	2-Methyl-4-chlorophenoxyacetic acid	25
64	3-Methylsulfonylphenoxyacetic acid	0
65	2-Nitrophenoxyacetic acid	0
66	3-Nitrophenoxyacetic acid	0.2
67	4-Nitrophenoxyacetic acid	0.1
68	2,4-Dinitrophenoxyacetic acid	0
69	2-Phenylphenoxyacetic acid	0
70	4-Phenylphenoxyacetic acid	0
71	α-Methyl-γ-phenoxybutyric acid	0
72	γ-Phenoxybutyronitrile	0
73	α-Phenoxypropionic acid	0.5
	Phenyl compounds	
74	Phenylacetic acid	1
75	α-Aminophenylacetic acid	0
76	4-Aminophenylacetic acid	0.05
77	4-Chlorophenylacetic acid	1
78	3-Fluorophenylacetic acid	1.5
79	4-Fluorophenylacetic acid	1.5
80	2,5-Dihydroxyphenylacetic acid	0.02
81	3-Iodophenylacetic acid	10
82	4-Iodophenylacetic acid	0
83	2,4-Dimethylphenylacetic acid	0.5
84	3,5-Dimethylphenylacetic acid	0.5
85	2,4,6-Trimethylphenylacetic acid	0
86	4-Nitrophenylacetic acid	0
87	4-Phenylphenylacetic acid	0
88	Diphenylacetic acid	0
89	Phenylacetonitrile	2
90	γ-Phenylbutyric acid	1.5
91	*N*-Phenylglycine	0.05
92	4-Chlorophenylglycine	1
93	Phenylpropiolic acid	0
94	2-Chlorophenylpropiolic acid	0
95	3-Chlorophenylpropiolic acid	0
96	4-Chlorophenylpropiolic acid	0
97	β-Phenylpropionic acid	0
98	*S*-Phenylthioglycolic acid	0.07
99	4-Chlorophenylthioglycolic acid	0.5
	Benzoic acids	
100	Benzoic acid	0
101	2-Acetoxybenzoic acid	0
102	2-Aminobenzoic acid	0
103	2-Amino-3,5-diiodobenzoic acid	0
104	2-Bromobenzoic acid	0.1
105	3-Bromobenzoic acid	0
106	4-Bromobenzoic acid	0
107	2-Chlorobenzoic acid	0.05
108	3-Chlorobenzoic acid	0
109	4-Chlorobenzoic acid	0
110	2,4-Dichlorobenzoic acid	0
111	2,5-Dichlorobenzoic acid	1
112	2,6-Dichlorobenzoic acid	0.1
113	Pentachlorobenzoic acid	0
114	2-Chloro-4-fluorobenzoic acid	0
115	2-Chloro-6-fluorobenzoic acid	0.1

continued

92. RELATIVE ACTIVITY OF GROWTH REGULATORS: PLANTS

Part I. CELL ELONGATION OF OAT COLEOPTILES

	Compound	Activity Index
	(A)	(B)
	Benzoic acids	
116	2-Chloro-5-nitrobenzoic acid	0
117	4-Ethyl-3-mercaptobenzoic acid	0
118	2-Fluorobenzoic acid	0
119	2,5-Difluorobenzoic acid	0
120	2-Fluoro-5-aminobenzoic acid	0
121	2-Fluoro-5-chlorobenzoic acid	0
122	2-Fluoro-3,5-dichlorobenzoic acid	0
123	2-Trifluoromethylbenzoic acid	0
124	2-Iodobenzoic acid	0
125	2,3,5-Triiodobenzoic acid	50
126	3,4,5-Triiodobenzoic acid	0
127	2,6-Dimethylbenzoic acid	0.05
128	2,6-Dimethyl-3-bromobenzoic acid	3
129	2,6-Dimethyl-3-chlorobenzoic acid	2
130	2,6-Dimethyl-3-iodobenzoic acid	2.5
131	2,6-Dimethyl-3-nitrobenzoic acid	0.1
132	2,4,6-Trimethylbenzoic acid	0
133	2-Nitrobenzoic acid	0.1
	Miscellaneous compounds	
134	Adamantine-1-acetic acid	0
135	Azulene-1-acetic acid	1
136	Azulene-1-acetonitrile	4
137	Azulene-1-carboxylic acid	0
138	Benzothiazyl-2-oxyacetic acid	0.5
	Miscellaneous compounds	
139	Carboxymethyl dimethyldithiocarbamate	0.5
140	Ethoxycarbonylmethyl dibutyldithiocarbamate	0
141	Ethoxycarbonylmethyl diethyldithiocarbamate	0.1
142	Ethoxycarbonylmethyl dimethyldithiocarbamate	1
143	1-Cyclohexenylacetic acid	0.1
144	Δ-1-Cyclopentenylacetic acid	0
145	Ferroceneacetic acid	0
146	Ferrocenediacetic acid	0
147	Ferrocenepropionic acid	0
148	Gibberellic acid	100
149	5-Indanyloxyacetic acid	0
150	1-Naphthaleneacetic acid	50
151	1-Naphthaleneacetonitrile	100
152	1-Naphthoic acid	0
153	2-Naphthoxyacetic acid	0.7
154	2-Phenanthreneacetic acid	0
155	3-Pyridoxyacetic acid	0
156	3-Pyridylacetic acid	0.01
157	Quinoline-5-oxyacetic acid	0
158	Quinoline-6-oxyacetic acid	0
159	5-Chloroquinoline-6-oxyacetic acid	0
160	5-Chloroquinoline-8-oxyacetic acid	0
161	8-Chloroquinoline-5-oxyacetic acid	0

Contributor: Muir, Robert M.

References: [1] Muir, R. M., and C. Hansch. 1953. Plant Physiol. 28:218. [2] Muir, R. M., and C. Hansch. 1955. Ann. Rev. Plant Physiol. 6:157. [3] Muir, R. M., and C. Hansch. 1961. Plant Growth Regulation, Intern. Conf., 4th, Yonkers, N. Y., 1959, p. 249. [4] Muir, R. M., and C. Hansch. 1961. Nature 190:741. [5] Muir, R. M., C. Hansch, and J. Gally. 1961. Plant Physiol. 36:222.

Part II. STEM CURVATURE OF SLIT PEA AND LEAF EXPANSION OF BEAN

	Compound	Slit Pea Stem Curvature[1]	Bean Leaf Expansion[2]
	(A)	(B)	(C)
	Indole acids		
1	3-Indoleacetic acid	100	<18
2	β-(3-Indole)-propionic acid	....	<19
3	γ-(3-Indole)-butyric acid	190	<40
	Phenoxy compounds		
4	Phenoxyacetic acid	0	<11
5	2-Bromophenoxyacetic acid	....	<23
6	4-Bromophenoxyacetic acid	....	6,160
7	2,4-Dibromophenoxyacetic acid	....	11,500
8	2,4,6-Tribromophenoxyacetic acid	0.1	....
9	2-Chlorophenoxyacetic acid	4	<19
10	3-Chlorophenoxyacetic acid	....	<37
11	4-Chlorophenoxyacetic acid	200	18,700
12	2,4-Dichlorophenoxyacetic acid	200-1,200	23,500
13	2,5-Dichlorophenoxyacetic acid	15	<69
14	2,6-Dichlorophenoxyacetic acid	3-4	137
	Phenoxy compounds		
15	3,5-Dichlorophenoxyacetic acid	<0.05	<44
16	2,4,5-Trichlorophenoxyacetic acid	500	<4,740
17	2,4,6-Trichlorophenoxyacetic acid	0.4	294
18	2,3,4,6-Tetrachlorophenoxyacetic acid	1	....
19	2,4-Difluorophenoxyacetic acid	12	5,360
20	2,4-Diiodophenoxyacetic acid	....	344
21	4-Chloro-2-methylphenoxyacetic acid	500	513
22	2,4,6-Trimethylphenoxyacetic acid	0	....
23	DL-α-(2,4-Dichlorophenoxy)-propionic acid	600	16,800

/1/ Expressed as percent of activity of 3-indoleacetic acid [4]. /2/ Activity expressed as reciprocal of dose (micromoles) causing 50% repression of leaf expansion [2].

continued

92. RELATIVE ACTIVITY OF GROWTH REGULATORS: PLANTS

Part II. STEM CURVATURE OF SLIT PEA AND LEAF EXPANSION OF BEAN

	Compound	Slit Pea Stem Curvature[1]	Bean Leaf Expansion[2]
	(A)	(B)	(C)
	Phenoxy compounds		
24	D-α-(2,4-Dichlorophenoxy)-propionic acid	1,200	....
25	β-(2,4-Dichlorophenoxy)-propionic acid	....	<47
26	γ-(2,4-Dichlorophenoxy)-butyric acid	....	18,500
27	*n*-Butyl 2,4-dichlorophenoxyacetate	....	23,100
28	2,4-Dichlorophenoxyacetyl-chloride	....	19,900
29	2,4-Dichlorophenoxyacetamide	....	7,760
30	2,4-Dichlorophenoxyacetanilide	....	30,800
31	2,4-Dichlorophenoxyethanol	....	22
32	2,4-Dichlorophenoxyethylamine	....	296
33	2,4-Dichlorophenoxythioacetic acid	....	20,300
	Phenyl acids		
34	Phenylacetic acid	3-6; 10	<3
35	γ-Phenylbutyric acid	2	....
36	4-Bromophenylbutyric acid	15	....
37	2,4-Dichlorophenylacetic acid	15	....
38	*N*-(2,4-Dichlorophenyl)-glycine	....	2.04
39	*S*-(2,4-Dichlorophenyl)-thioglycolic acid	....	<47
40	2,4-Dinitrophenylacetic acid	0.1	<23
41	Phenylthioacetic acid	0	....
42	4-Chloro-2-methylphenylthioacetic acid	200	....
	Benzoic acids		
43	2-Chlorobenzoic acid	....	<5
44	3-Chlorobenzoic acid	....	<15
45	4-Chlorobenzoic acid	....	<8
46	2,4-Dichlorobenzoic acid	0	<19
47	2,5-Dichlorobenzoic acid	....	204
48	3,4-Dichlorobenzoic acid	0	<19
49	2,3,5-Trichlorobenzoic acid	....	2,130
50	2,3,6-Trichlorobenzoic acid	200	....
51	3,4,5-Trichlorobenzoic acid	....	<45
	Naphthalene compounds		
52	1-Naphthaleneacetic acid	250; 370	<100
53	2-Naphthaleneacetic acid	100	<19
54	1-Naphthaleneacetamide	10	....
	Naphthoxy compounds		
55	1-Naphthoxyacetic acid	....	<40
56	2-Naphthoxyacetic acid	....	319
57	1-Naphthoxyacetamide	....	25
	Reference	1, 3-5	2, 6

/1/ Expressed as percent of activity of 3-indoleacetic acid [4]. /2/ Activity expressed as reciprocal of dose (micromoles) causing 50% repression of leaf expansion [2].

Contributors: Brown, James W., and Weintraub, Robert L.

References: [1] Bonner, J. 1950. Plant biochemistry. Academic Press, New York. [2] Brown, J. W., and R. L. Weintraub. 1950. Botan. Gaz. 111:448. [3] Thimann, K. V. 1951. In F. Skoog, ed. Plant growth substances. Univ. Wisconsin Press, Madison. p. 32. [4] Thimann, K. V. 1952. Plant Physiol. 27:392. [5] Thimann, K. V. Unpublished. Harvard Univ., Cambridge, 1953. [6] Weintraub, R. L., J. W. Brown, and J. A. Throne. Unpublished. Fort Detrick, Maryland, 1953.

93. ANTIMETABOLITES

	Metabolite	Antimetabolite[1]	Structural Alteration	Alteration Affects
	(A)	(B)	(C)	(D)
1	Acetic acid	Fluoroacetic acid	F for H	....
2	Adenine	Benzimidazole & derivatives	2 C for 2 N; side-chain alterations	Microorganisms, animals
3		Triazolopyrimidines	N for C	Microorganisms, animals
4		Diaminopurine	NH_2 for H	Bacteria, animals
5	α-Alanine	Glycine	H for CH_3	Bacteria
6	β-Alanine	β-Aminobutyric acid	CH_3 for H	Yeast
7		Propionic acid	H for NH_2	Bacteria
8		Asparagine	COOH for H; $CONH_2$ for COOH	Yeast
9	*p*-Aminobenzoic acid	Sulfanilamide & derivatives	SO_2NH_2 or derivatives for COOH	Microorganisms
10		*p*-Aminobenzamide	$CONH_2$ for COOH	Bacteria
11		Carbarsone & related arsenicals	Arsenic for C in a COOH group; derivatives	Microorganisms, animals
12		Phosphanilic acid	PO_3H_2 for COOH	Microorganisms
13		Heterocyclic acids[2]	N or S for C	Bacteria
14		Ring-substituted PAB	Halogen or alkyl for H	Bacteria

/1/ Structural analog. /2/ E.g., 6-aminonicotinic acid.

continued

93. ANTIMETABOLITES

	Metabolite	Antimetabolite[1]	Structural Alteration	Alteration Affects
	(A)	(B)	(C)	(D)
15	*p*-Aminobenzoic acid	*p*-Aminoacetophenone & derivatives	COR for COOH	Bacteria
16		*p*-Nitrobenzoic acid	NO_2 for NH_2	Bacteria
17	Arginine	Canavanine	O for CH_2	Bacteria
18	Ascorbic acid	Glucoascorbic acid	Addition of CHOH & optical inversion	Animals, liver enzymes
19	Aspartic acid	Hydroxyaspartic acid	OH for H	Bacteria
20		Aspartophenone	C_6H_5 for OH	Bacteria
21	Biotin	Desthiobiotin & derivatives	2 H for S	Microorganisms
22		Biotin sulfone	SO_2 for S	Microorganisms
23		Ureylenecyclohexyl aliphatic acids	2 C for S; derivatives with shorter side chains	Microorganisms
24		Desthioisobiotin	Loss of S, geometric isomerism	Insects
25		Ureylenetetrahydrofuryl aliphatic sulfonic acids	O for S, SO_3H for COOH	Microorganisms
26		Homobiotin	Addition of $-CH_2-$	Microorganisms
27	Choline	Triethyl choline	3 ethyls for 3 methyls	Frog muscle, mice
28	Cocarboxylase	Thiaminethiazole pyrophosphate	Loss of pyrimidine portion	Carboxylase
29	Cytidine	Adenosine	OH for H, loss of imidazole ring	*Neurospora* mutant
30	Desthiobiotin	2-Oxyimidazole aliphatic acids	H for CH_3	Microorganisms
31	Glutamic acid	Methionine sulfoxide	$SOCH_3$ for COOH	Bacteria
32		Hydroxyglutamic acid	OH for H	Bacteria
33		*N*-Alkylglutamines	*N*-Alkyl for OH	Bacteria
34	Guanine	Triazolopyrimidines	N for C	Bacteria
35		Benzimidazole	2 C for 2 N	Microorganisms
36	Histamine	Imidazole & derivatives	Elimination or substitution of part of molecule	Smooth muscle, histamine shock in animals
37		Diphenhydramine	Opening of ring, O for N, alkylation of N, C	Smooth muscle, histamine shock in animals
38		Tripelennamine	Opening of ring, alkylation of N	Smooth muscle, histamine shock in animals
39	Hypoxanthine	Hydroxytriazolopyrimidine	N for C	Bacteria
40	Indoleacetic acid	Phenyl butyric acid	Elimination of N and shift of 1 C	Plants
41		Skatyl sulfonic acid	SO_3H for COOH	Plants
42	Inositol	Hexachlorocyclohexane	6 Cl for 6 OH	Fungi, plants, pancreatic amylase
43	Isoleucine	Leucine	Position isomerism of 1 CH_3	Bacteria
44	Leucine	D-Leucine	Optical inversion	Bacteria
45	Lysine	Arginine	Guanidino for amino, elimination of CH_2	*Neurospora* mutant
46	Methionine	Methoxinine	O for S	Bacteria
47		Ethionine	CH_3 for H	Bacteria and animals
48		Norleucine	CH_2 for S	Bacteria
49	Nicotinic acid (or amide)	Pyridine-3 sulfonic acid or amide	SO_3H for COOH	Microorganisms, animals[3]
50		3-Acetylpyridine	$COCH_3$ for COOH	Animals; not microorganisms
51		5-Thiazole carboxamide	S for CH=CH	Certain bacteria
52	Pantothenic acid	Thiopanic acid (pantoyltaurine) & derivatives	SO_3H and derivatives for COOH	Microorganisms, pantothenate-utilizing enzymes; not animals
53		Pantothenyl alcohol	CH_2OH for COOH	Microorganisms; not animals
54		α- or β-Methyl pantothenic acid	CH_3 for H	Microorganisms
55		Other substituted pantoamides	Alkyl or OH- and NH_2-alkyl for CH_2CH_2COOH	Microorganisms
56		Phenyl pantothenone	COC_6H_5 for COOH	Microorganisms
57		Salicylyl β-alanine	*o*-Hydroxy-benzoyl for pantoyl	Microorganisms
58		γ'-Methyl pantothenic acid	CH_3 for H	Bacteria
59	Phenylalanine	β-Hydroxyphenylalanine	OH for H	Bacteria
60		Thienylalanine	S for CH=CH	Microorganisms, animals
61		Furylalanine	O for CH=CH	Microorganisms
62		Halogenated phenylalanines	Halogen for H	Microorganisms
63	Pimelic acid	2, 4-Dichlorosulfanilidocaproic acid	Dichlorosulfanilide for COOH	Biotin-independent microorganisms

/1/ Structural analog. /3/ Animal alcohol and lactic dehydrogenases, not animals in vivo.

continued

93. ANTIMETABOLITES

	Metabolite (A)	Antimetabolite[1] (B)	Structural Alteration (C)	Alteration Affects (D)
64	Porphyrins[4]	Porphyrins lacking vinyl groups		Bacteria
65	Pteroylglutamic acid	Pteroyltriglutamic acid	Addition of two glutamic acids	Transplanted tumors
66		Xanthopterin	Loss of *p*-aminobenzoyl glutamic acid	Transplanted tumors
67	Pyridoxine	Deoxypyridoxine	H for OH	Microorganisms, animals
68		2-Ethyl-3-amino-4-ethoxymethyl-5-amino-methyl pyridine	CH_3 for H, NH_2 for OH, Et for H	Microorganisms
69	Riboflavin	6,7-Dichlororiboflavin	2 Cl for 2 CH_3	Microorganisms
70		Isoriboflavin	Shift in position of CH_3	Animals; not bacteria
71		Corresponding phenazine	2 C for 2 N, 2 NH_2 for 2 OH	Microorganisms, animals
72		Galactoflavin	Dulcityl for ribityl	Animals
73		Lumiflavin	CH_3 for ribityl	Bacteria
74		Araboflavin	Inversion of position of OH	Animals
75	Succinic acid	Malonic acid	Loss of CH_2	Succinic oxidase
76		Sulfonated succinic acid	SO_3H for H	Succinic oxidase
77	Testosterone	Estradiol	Benzene ring for cyclohexane ring, loss of CH_3	Animals
78	Thiamine	Pyrithiamine	CH=CH for S	Microorganisms, animals
79		Oxythiamine	OH for NH_2	Animals, fish thiaminase
80		Butylthiamine	Butyl for CH_3	Animals
81		Aminobenzyl-methylthiazolium chloride	2 C for 2 N, loss of side chains	Fish thiaminase
82	Thymine	5-Substituted dioxypyrimidines	NO_2 or Br or NH_2 or OH for CH_3	Bacteria
83		2,4-Diamino- or dithiothymine	NH_2 or SH for OH	Bacteria
84	Thyroxine	Ethers of diiodotyrosine	*p*-Nitrobenzyl or *p*-nitrophenylethyl or benzyl for *p*-hydroxydiiodophenyl	Tadpoles
85	α-Tocopherol	α-Tocopherol quinone	Opening of ring by addition of O	Animals
86	Tryptophan	Indole of acrylic acid	Loss of NH_3	Bacteria
87		Naphthylacrylic acid	Loss of NH_3, C=C for N	Bacteria
88		Styrylacetic acid	Loss of NH_2, substitution of aliphatic unsaturated side chain for pyrrole ring	Bacteria
89		Methyltryptophans	CH_3 for H	Bacteria
90		Benzothienylalanine	S for N	Bacteria
91		Indole	Loss of side chain	Bacteriophage plus bacteria
92	Tyrosine	3-Fluorotyrosine	F for H	Rats
93	Uracil	Barbituric acid	OH for H	Bacteria
94		Thiouracil	S for O	Bacteria, plant seed germination
95	Vitamin K	Dicumarol & derivatives	O for C, side-chain alterations	Animals
96		Iodinin	2 N for 2 C, side-chain alterations	Bacteria
97		α-Tocopherol quinone	2 CH_3 for benzene ring	Animals
98		2,3-Dichloronaphthoquinone	2 Cl for alkyl side chains	Microorganisms
99		2-Substituted-3-hydroxynaphthoquinones	OH for H, change in alkyl substituent	Animals; not bacteria
100		Methoxynaphthoquinone	OCH_3 for CH_3	Microorganisms

/1/ Structural analog. /4/ E.g., hematin and protoporphyrin.

Contributor: Woolley, D. W.

Reference: Woolley, D. W. 1952. A study of antimetabolites. J. Wiley, New York. pp. 33-36.

Abbreviations: d. = decomposes; s. = soluble; i. = insoluble; sl. = slightly; l. = less;

	Antibiotic (Synonym)	Source	Molecular Formula and Weight	Nature	Crystal Form and Color
	(A)	(B)	(C)	(D)	(E)
1	Actinomycins	*Streptomyces* spp.	Varies with the amino acid content	Chromopeptides differing in amino acid portions of the molecule; usually occur naturally as mixtures of two or more components	Red or yellow-red plates, prisms, or needles
2	Amphotericin B[1]	*Streptomyces nodosus*	$C_{46}H_{73}NO_{20}$; 959 (neut. equiv.)[2]	Amphoteric conjugated heptaene	Deep yellow prisms or needles from dimethyl formamide
3	Bacitracins (Ayfivin)	*Bacillus subtilis, B. licheniformis*	Bacitracins A: $C_{66}H_{103}O_{16}N_{17}S$; 1,470±10% (actual) Bacitracins B: $C_{71}H_{112}O_{17}N_{18}S$	Weakly basic polypeptides	White, highly hygroscopic, amorphous powder
4	Carbomycin[4] (Antibiotic M 4209)	*Streptomyces* spp.	$C_{42}H_{67}NO_{16}$; 842 (calc.); 830-860 (neut. equiv.)	Monobasic macrolide	Slender, white, blunt-ended, needle-shaped crystals; colorless laths from ethanol; rectangular plates from ethanol-water
5	Chloramphenicol (Antibiotic 8-44; Levomycetin; Sintomicetin; Synthomycin)	*Streptomyces venezuelae;* by synthesis	$C_{11}H_{12}N_5O_2Cl_2$; 323 (calc.); 310 (Rast)	Neutral	Colorless, elongated plates or fine needles
6	Colistin[5]	*Bacillus colistinus*	$C_{45}H_{85}N_{13}O_{10}$; 1200±50; about 969 (actual)	Heteromeric decapeptide	Colorless
7	Erythromycin[6] (Erythromycin A)	*Streptomyces erythraeus*	$C_{37}H_{67}NO_{13}$; 733.9 (calc.)	Basic macrolide	Whi s
8	Griseofulvin	*Penicillium* spp.; by synthesis	$C_{17}H_{17}O_6Cl$; 309-398 (actual); 352.5 (calc.)	Neutral	Massive colorless rhombic or octahedral crystals from benzene
9	Kanamycins[8]	*Streptomyces kanamyceticus*	Kanamycin A: $C_{18}H_{36}N_4O_{11}$; 427-490 (actual) Kanamycin B: $C_{16}H_{32}N_4O_{10}$; 385-560 (Barger); 463.3 (calc.) Kanamycin C[9]: $C_{18}H_{36}N_4O_{11}$; 415-625 (Barger)	Basic	Base: fine colorless needles Sulfate: small, irregular, white, prismatic crystals after repeated crystallization
10	Neomycins[10]	*Streptomyces* spp.	Complex: $C_{23}H_{46}N_6O_{13}$; 507-669 (ebull.)	Basic	Sulfate, HCl, and free base: colorless amorphous solids
11	Novobiocin	*Streptomyces griseoflavus, S. niveus, S. spheroides*	$C_{31}H_{36}N_2O_{11}$; 592±25 (ebull.); 610 (Rast); 618 (X ray)	Dibasic acid	White to cream-colored amorphous solid or pale yellow crystals (two crystalline forms, I and II)
12	Nystatin (Fungicidin)	*Streptomyces noursei;* other *Streptomyces* species	$C_{46}H_{77}O_{19}$; 933 (calc.)	Amphoteric conjugated tetraene	Pale yellow microcrystals or needles

/1/ The same *Streptomyces* culture produces amphotericin A, a conjugated tetraene antifungal agent [46, 47]. /4/ Carbomycin B occurs in beers of *Streptomyces halstedii* [68]. /5/ Identical with polymyxin E [132]. /6/ Erythpartially resolidifies and then melts at 190-193°C [54]. /8/ A complex of kanamycins A, B, and C [90, 105]. /9/ Isoyears, under refrigeration [21].

ANTIBIOTICS

CHEMICAL CHARACTERISTICS

v. = very; calc. = calculated; neut. equiv. = neutral equivalent; ebull. = ebullient.

Melting Point °C (F)	Solubility (G)	Stability (H)	Reference (I)	
215-255 d.	s. benzene, ethanol acetone; sl.s. water, ether; i. aqueous dilute mineral acids and alkalies, petroleum ether	Thermostable at pH 6-7; relatively stable at acid pH; unstable at alkaline pH	126,127	1
Gradual decomposition above 170	s. dimethyl sulfoxide, acetic *N,N*-dimethylformamide; sl.s. propylene glycol, glacial acetic acid, *N,N*-dimethylformamide; i. water, chloroform, methanol, ether, pyridine, alcoholic KOH	Dry solids stable for long periods at moderate temperatures; undergoes decomposition in solution at pH 4-10	B,46,47;C,E-G, 45;D,H,120	2
	s. methanol, ethanol, water; sl.s. acetone, cyclohexanone, propanols, butanols, pyridine; i. ether, chloroform, benzene, acetone, ethyl acetate, petroleum ether	Relatively thermostable, especially at pH 4 and 5; unstable above pH 9; aqueous solutions unstable after storage at room temperature[3]	B,73;C,29,30;D,9, 28;E,9;G,H,6, 15,73	3
210-218 d.	Acid salts: s. water, most organic solvents Base: i. water, hexane	Most stable at pH 5-7 (11 days at 25°C); stable for several months in dark at room temperature; unstable below pH 3 and above pH 9	B,51,72,115;C,44, 51,72;D,44,51, 115,133;E,51, 115,121;F,H,44, 51,121;G,115,121	4
149.7-150.7	s. propylene glycol, methanol, ethanol, butanol, ethyl acetate, acetone, diethyl ether; sl.s. chloroform, water, alkali; i. acid, benzene, petroleum ether, vegetable oils	Thermostable; alkali labile	B,27,48,80;C,11, 101;D,10,48,60, 101;E,10,48,57;F,10,11,48, 57,101;G,10,48,57,60,101; H,10,11,48,57	5
Base: 245-249 d. Phosphate: 145	s. water, lower alcohols	Stable at 40°C for at least 60 days; salt solutions stable at pH 2-6, less stable above pH 6	B,E,F,79;C,G,79, 106;D,33	6
Complex: 82-83.5 Base: 136-140[7] HCl: 170-173	s. alcohols, acetone, chloroform, acetonitrile, ethyl acetate; l.s. ether, ethylene dichloride, amyl acetate, water HCl: v.s. water, lower alcohols	Stable at -25° to +4°C; stable 4 days at 37°C; unstable at 60° or 100°C	B,84;C,130;D,84, 130;E,F,54;G,54, 84;H,62	7
220-221	s. *N,N*-dimethylformamide 12-14% at room temperature, acetic acid, dioxane, benzene, ether, ethanol; sl.s. chloroform, ethyl acetate, toluene, acetone, ligroin; i. water, petroleum ether	Thermostable	B,20,35,116,118; C,59,93;D,E,93; F,59;G,8,93;H, 18	8
Decompose over a wide range	Base: s. water; sl.s. lower alcohols; i. nonpolar solvents HCl: v.s. water; s. methanol; sl.s. ethanol; i. acetone, ethyl acetate, butyl acetate, ether, benzene	Thermostable, especially at neutral pH	B,119;C,32,85,89, 122;D,32;E,32, 89,122;F,32,90, 105,122;G,32, 105,122;H,31,58	9
	s. water; i. organic solvents	Thermostable; crude neomycin stable at pH 2-9; highly purified preparations stable to alkali only	124,125	10
I: 152-156 d. II: 174-178 d.	s. methanol, ethanol, butanol, acetic acid, dioxane, water above pH 7.5; i. water below pH 7.5, ether, benzene, carbon tetrachloride, chloroform Mono- and di-sodium salts: v.s. water	Dry material stable at 24°C in absence of light; dilute aqueous solutions stable at pH 2 at 24°C; half-life, 60 days at pH 7-10	B,111,128;C,67, 69,74;D,F,69,74; E,69,74,88;G,88; H,70	11
Gradual decomposition above 160 without melting at 250	s. *N,N*-dimethylformamide, *N,N*-dimethylacetamide, propylene glycol; l.s. methanol, aqueous *n*-propanol or isopropanol, water-saturated butanol; i. water, most organic solvents	Unstable; most stable as a dry powder[11]; aqueous suspensions less stable than alcoholic solutions; aqueous suspensions stable at least eight months at -25°C	B,65;C,G,21;D,F, 107;E,43	12

/2/ Perchloric acid in acetic acid [45]. /3/ Bacitracin F, a transformation product, is formed above pH 7 [30, 64]. romycins B and C also occur in same fermentation liquors [131]. /7/ If slow rate of heating continues, compound meric with kanamycin A [89]. /10/ A complex of neomycins B and C which are isomeric [125]. /11/ At least $4\frac{1}{2}$

continued

	Antibiotic (Synonym)	Source	Molecular Formula and Weight	Nature	Crystal Form and Color
	(A)	(B)	(C)	(D)	(E)
13	Oleandomycin (Antibiotic PA 105)	*Streptomyces antibioticus*	$C_{35}H_{61}NO_{12}$; 715 (ebull.); 687.84 (calc.)	Basic macrolide	Long white needles; colorless prisms
14	Paromomycin (Aminosidin; Catenulin; Hydroxymycin)	*Streptomyces* spp.	$C_{23}H_{45}N_5O_{14}$	Basic	Amorphous; white
15	Penicillins			Strong monobasic carboxylic acid	
16	Ampicillin	Semisynthetic	$C_{16}H_{19}N_3O_4S$		Fine needles
17	Benzylpenicillin (Penicillin G)	*Penicillium* spp.; *Aspergillus* spp.	$C_{16}H_{18}N_2O_4S$; 331 (actual)		Colorless prisms
18	Cephalosporin N (Penicillin N; Synnematin B)	*Cephalosporium* spp.; *Streptomyces* sp.	$C_{14}H_{21}N_3O_6S$	A hydrophilic penicillin	Ba salt; white powder
19	Methicillin	Semisynthetic	Sodium salt: $C_{17}H_{19}N_2O_6SNa$		White crystalline solid
20	Oxacillin	Semisynthetic	Sodium salt: $C_{19}H_{18}N_3O_5SNa$		
21	Phenethicillin	Semisynthetic	Potassium salt: $C_{17}H_{19}N_2O_5SK$; 402.51		Colorless crystals
22	Phenoxymethylpenicillin (Penicillin V)	*Penicillium notatum*	Potassium salt: $C_{16}H_{17}N_2O_5SK$		
23	Polymyxins	*Bacillus polymyxa*	Polymyxin $B_1 \cdot 5HCl$: $C_{56}H_{104}N_{16}O_{14}Cl_5$; 1,150±10% (actual) Polymyxin $D \cdot 4HCl$: $C_{50}H_{97}N_{15}O_{15}Cl_4$; 1,150 (actual); 1,144 (calc.) Average for A, B, D, E: 1,250 (actual)	Basic polypeptides	Birefringent; no definite structure
24	Ristocetins[12]	*Nocardia lurida*	Ristocetin A: 2,500 (freezing point depression); 5,000 (ultracentrifuge)	Amphoteric	A sulfate: hexagonal prismatic rods B sulfate: needles
25	Spiramycins[13] (Antibiotic R.P. 5337; Foromacidins; Sequamycin)	*Streptomyces ambofaciens*	I: $C_{45}H_{78}N_2O_{15}$; 886 (calc.) II: $C_{47}H_{80}N_2O_{16}$; 928 (calc.) III: $C_{48}H_{82}N_2O_{16}$; 942 (calc.)	Basic macrolides	Complex: amorphous white powder
26	Streptomycin	*Streptomyces* spp.	$C_{21}H_{39}N_7O_{12}$; 581.58 (calc.)	Strongly basic	Reineckate: thin plates Helianthate: dark red crystals HCl: white amorphous powder Tri-HCl: monoclinic prisms
27	Streptovaricin[14]	*Streptomyces spectabilis*			Partially crystalline; bright orange-yellow

/12/ Two components distinguishable by paper chromatography; B is three-to-four times as active as A [98]. /13/ The five components [110].

CHEMICAL CHARACTERISTICS

Melting Point °C	Solubility	Stability	Reference	
(F)	(G)	(H)	(I)	
Base: 110 d. Chloroform solvate: 120-121	Base: s. most organic solvents, acidic media; sl.s. water, ligroin HCl: v.s. water	Stable at room temperature pH 2-9 in aqueous solution; unstable when heated at acid pH	B,112;C,49,72, 113;D,49,72;E, 49,113;F,G,49; H,112,113	13
	v.s. water; l.s. methanol; sl.s. absolute ethanol; i. other organic solvents	Stable in aqueous solutions at pH 1.5-10.0	B,7,55,61;C,D,7, 104;E,55;G,7,55; H,34	14
	Acids: s. alcohols, ketones, ethers, esters, aromatic hydrocarbons; sl.s. water; i. aliphatic hydrocarbons Na salts: s. water, methanol, ethanol; sl.s. dry butanol, ketones, ethyl acetate		24,53	15
202 d.	Free acid: sl.s. water; more s. in alkaline solutions	Acid stable; unstable to penicillinase	B,C,E,F,39;G,H, 77	16
Na salt: 215 d.		Labile to acids, heat, penicillinase	24,53	17
	i. most organic solvents Ba salt: s. water; sl.s. methanol; i. ethanol	Unstable at room temperature below pH 4 and above 9; unstable at pH 7 in presence of heavy metal ions; unstable to penicillinase	B,D,1,3;C,1,91;E, 2;G,2,3;H,3,91	18
		Unstable to acid; stable to penicillinase	B,H,37,76,77;C, 37;E,37,103	19
Hydrated Na salt: 188 d.		Acid stable; stable to penicillinase	38	20
K salt: 230-231 d.		Acid stable; unstable to penicillinase	B,C,78,97;E,F,97; H,78	21
K salt: 263 d.		Acid stable; unstable to penicillinase	B,53,95;C,109;F, 108;H,56,95	22
228-235 d.	Base: sl.s. water; i. alcohol HCl: s. water, methanol; l.s. higher alcohols; i. ether, esters, hydrocarbons, chlorinated solvents	Thermo- and acid-stable; alkali unstable	B,4;C,14,50,63;D, 22;E,100;F,G, 14,23;H,23	23
	s. acidic aqueous solution; l.s. at neutral pH; i. organic solvents Bases are less water-soluble than salts	Stable at acid pH; unstable at alkaline pH	98	24
I: 134-137 II: 130-133 III: 128-131	Base: s. most organic solvents; sl.s. water Sulfate: s. water, lower aliphatic alcohols	Biological activity lost on acid hydrolysis	B,E,G,99;C,72,96; D,72,99;F,H,96	25
Reineckate: 164-165 d. Helianthate: 220-226 d. Tri-HCl: gradual decomposition without melting	s. water; sl.s. lower alcohols; i. other organic solvents	Stable at pH 3-7; less stable to heat, acid, alkali	123	26
144-147 d.	v.s. *N,N*-dimethylformamide, 95% ethanol; s. methanol, butanol, lower ketones, methylene chloride, chloroform, lower acetates; sl.s. water; i. hexane, ether, carbon tetrachloride, benzene	Biological activity destroyed in alkaline solution	B,110;E-H,129	27

three components I, II, and III are identical with foromacidins A, B, and C [96]. /14/ A complex containing at least

continued

	Antibiotic (Synonym)	Source	Molecular Formula and Weight	Nature	Crystal Form and Color
	(A)	(B)	(C)	(D)	(E)
	Tetracyclines				
28	Chlortetracycline	*Streptomyces aureofaciens*	$C_{22}H_{23}N_2O_8Cl$; 478.88 (calc.)	Amphoteric	Base: yellow, acicular to bladed crystals HCl: rhomboid; clear vitreous lemon-yellow
29	Demethylchlortetracycline	*Streptomyces aureofaciens*	$C_{21}H_{21}N_2O_8Cl$; 464.6 (calc.)	Amphoteric	Yellow crystals
30	Oxytetracycline	*Streptomyces rimosus, S. hygroscopicus*	$C_{22}H_{24}N_2O_9$; 460.43 (calc.)	Amphoteric	Anhydrous base: pale yellow substance Dihydrate: thick hexagonal plates or thick needles HCl: bright yellow needles from methanol or platelets from water
31	Tetracycline	*Streptomyces aureofaciens;* catalytic dehalogenation	$C_{22}H_{24}N_2O_8$; 444.43 (calc.)	Amphoteric	Trihydrate: yellow orthorhombic or equant to tabular crystals
	Tyrothricin[15]				
32	Gramicidin	Component of tyrothricin	$C_{148}H_{210}N_{30}O_{26}$; 2826 (calc.)	Mixture of neutral polypeptides	Colorless platelets with pointed or rectangular ends
33	Tyrocidine	Component of tyrothricin	Tyrocidine A: $C_{66}H_{86}N_{13}O_{13}$; 1270 (actual) Tyrocidine B: $C_{68}H_{88}N_{14}O_{13}$; 1346 (calc.)	Mixture of basic polypeptides	HCl: fine colorless needles or rods
34	Vancomycin	*Streptomyces orientalis*	HCl: 3,300 (estimated from sedimentation data) Base: 785 (minimum molecular wt) Sulfate: 2,013-2,238 (minimum molecular wt)	Amphoteric	HCl: white solid Base: crystalline rosettes

/15/ Composed of approximately 20% gramicidin and 80% tyrocidine, which in turn are mixtures of polypeptides [71];

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Melting Point °C	Solubility	Stability	Reference	
(F)	(G)	(H)	(I)	
Base: 168-169 d. HCl: decomposes above 210	Base: v.s. aqueous solutions above pH 8.5, dioxane, pyridine, cellosolves, carbitol; l.s. methanol, ethanol, butanol, acetone, ethyl acetate, benzene; i. ether, petroleum ether HCl: s. water, methanol; sl.s. ethanol	Most stable at pH 2.5; less stable at neutral and alkaline pH	B,41;C,114;D,19, 25,42,102;E,42; F,G,19,42;H,36, 52,102	28
Base: 170-175 d. Sesquihydrate: 174-178 d.	More water-soluble than other tetracyclines	More stable than other tetracyclines at acid pH, and oxytetracycline and chlortetracycline at alkaline pH	B,F,81,82;C,E,G, H,82;D,19,25,42, 102	29
Anhydrous base: 184.5-185.5 d. Dihydrate: 181-182 HCl: 190-194	Anhydrous base: s. methanol, ethanol, acetone, propylene glycol, dioxane; sl.s. water, butanol, 90% aqueous acetone, 95% methanol; i. ether, petroleum ether HCl: s. acetone, methanol, ethanol, other polar organic solvents; i. ether, petroleum ether	Most stable at pH 2.5; less stable at neutral and alkaline pH	B,52,117;C,102;D, 19,25,42,102; E-G,52,102;H, 36,52,102	30
Anhydrous base: 160-168 Trihydrate: 170-175 d. HCl: 214 d.	Trihydrate: v.s. methanol; s. ethanol, butanol, ethyl acetate, chloroform; sl.s. water, benzene, ether; i. petroleum ether HCl: s. water; l.s. methanol, ethanol; i. ether, hydrocarbons	More stable than chlortetracycline and oxytetracycline; most stable at acid pH	B,25,86,114;C,25, 26;D,19,25,42, 102;E,5,87;F,17, 25,26;G,16;H,86	31
228-248 (depends on last solvent present during drying)	s. chloroform, benzene, ethanol, acetone, hot ethyl acetate, 10% HCl; sl.s. water, ether; i. petroleum ether, dilute mineral acids, dilute alkali	Thermostable	B-E,G,H,71;F,92	32
240 d.	s. methanol, ethanol, acetic acid, pyridine (especially in presence of water); sl.s. water, dry acetone, dioxane; i. ether, hydrocarbons, chloroform, electrolytes	Thermostable	B,F-H,71;C,13, 75,94;D,E,12; F-H,71	33
	HCl: s. water; l.s. aqueous methanol; i. higher alcohols, acetone, ether	Most stable at pH 3-5; unstable at 37°C in glycine buffer at other than pH 3-5; 10% loss in six months at 5°C and pH 3-5	B,D,G,83;C,H,66; E,66,83	34

Bacillus brevis is source of tyrothricin [40].

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94. ANTIBIOTICS

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Part II. BIOLOGICAL ACTIVITY

	Antibiotic	Biological Activity	Clinical Results
	(A)	(B)	(C)
1	Actinomycins	**In vitro**: Inhibitory to gram-positive bacteria; less active against mycobacteria; virtually inactive against gram-negative bacteria and fungi. **In vivo**: Effectiveness in animals is limited by high toxicity, but there are several reports of activity on tumors. Many actinomycins cause splenic atrophy in animals after multiple doses. [54]	Short remissions have been obtained in Hodgkin's disease and chronic lymphatic leukemia with actinomycin C. Diarrhea, mucosal inflammation, alopecia, and liver damage have been noted. [3] Actinomycin D has produced a number of temporary remissions in carcinoma of the breast, malignant melanoma, and lymphosarcoma. Toxicity is similar to that produced with actinomycin C. [51]
2	Amphotericin B	**In vitro**: An antifungal agent which is most active against fungi possessing a yeast phase (apparently acts against oxidative metabolic processes). Activity, which is markedly influenced by pH, is reduced above pH 7.5. Inhibits *Blastomyces dermatitidis, Candida albicans, Cladosporium trichoides, Coccidioides immitis, Cryptococcus neoformans, Histoplasma capsulatum, Paracoccidioides brasiliensis* and the yeast phase only of *Sporotrichum schenckii*. **In vivo**: Biological cures have been limited mostly to cases in which drug administration occurred with, or shortly after, inoculation. [34,43,47]	Useful in treating such systemic mycoses as histoplasmosis, blastomycosis, coccidioidomycosis, and cryptococcosis. Usefulness in moniliasis has not been adequately established. Preferred route of administration is intravenous, but intrathecal or local instillations may be employed. Poor absorption from the gastrointestinal tract precludes oral administration. Mild reversible azotemia, anorexia, headache, chills and fever are common toxic manifestations. Other effects include anemia, intestinal disturbance, and rash. [34,43,47]
3	Bacitracins	**In vitro**: In general, active against gram-positive bacteria (especially micrococci); little or no activity against gram-negative organisms, *Bacillus subtilis*, or fungi. Little evidence of cross-resistance with other antibiotics. Bactericidal. **In vivo**: Controlled staphylococcal meningitis in dogs, *Treponema pallidum* in rabbits, clostridial infections in guinea pigs (if promptly administered), and pinworms in mice. [13,31]	Used in the topical therapy of superficial infections of the skin, mucous membranes, eye, ear, etc. Frequently combined with polymyxin or neomycin for specific drug-resistant staphylococcal sepsis. Amoebic colitis, dysentery due to various organisms, and pinworms treated successfully by oral administration. Nephrotoxicity and pain at site generally result from parenteral treatments. [13,23]
4	Carbomycin	**In vitro**: Bacteriostatic. Active mainly against gram-positive and a few gram-negative bacteria, large viruses, rickettsiae, and certain protozoa. Cross-resistance with erythromycin and other macrolides. *continued*	Useful in infections caused by gram-positive organisms resistant to penicillin, but seems to have no advantage over erythromycin in common pyogenic infections. Usually administered orally. Low toxicity, similar to that produced by erythromycin. [4,13]

continued

94. ANTIBIOTICS

Part II. BIOLOGICAL ACTIVITY

	Antibiotic (A)	Biological Activity (B)	Clinical Results (C)
	Carbomycin (*See preceding page*)	**In vivo:** Good protection against ***Diplococcus pneumoniae, Staphylococcus aureus, Pasteurella multocida, Clostridium tetani,*** many rickettsiae, the viruses of psittacosis, ornithosis, lymphogranuloma venereum, human and feline pneumonitis, and sporadic encephalomyelitis. Inactive against ***Bacillus anthracis, Mycobacterium tuberculosis.*** [13]	
5	Chloramphenicol	**In vitro:** Inhibits protein synthesis and is primarily bacteriostatic. Active against gram-positive and gram-negative bacteria, rickettsiae, and large viruses; no activity against fungi. Active against ***Borrelia*** spp., ***Entamoeba histolytica, Tritrichomonas foetus.*** **In vivo:** Active in a wide variety of infections caused by the organisms specified under "in vitro." [21,56]	Agent of choice in typhoid fever and some types of meningitis, notably ***Haemophilus influenzae*** meningitis. Commonly used in systemic infections caused by staphylococci, particularly those resistant to other drugs. Useful in treating rickettsial diseases, infections caused by resistant gram-negative enteric bacteria, and severe dysenteries. Administered orally or parenterally. Toxic manifestations have included gastrointestinal upset, hypersensitivity, and blood dyscrasias. [21,56]
6	Colistin	**In vitro:** Primarily bactericidal. Highly inhibitory for most strains of the coli-aerogenes, ***Pseudomonas, Salmonella,*** and ***Shigella*** groups, being more active than polymyxin B. Inhibits some species of ***Candida*** and certain other fungi. Most strains of ***Proteus, Neisseria,*** and gram-positive organisms are resistant. **In vivo:** Colistinmethanesulfonate is less toxic in mice, but not in rats, than the sulfate. Both compounds are highly effective orally or parenterally against ***Escherichia coli*** or ***Klebsiella pneumoniae*** infections in mice. [42,57]	Colistin sulfate, administered orally, is particularly effective in infectious infant enteritis. Intramuscular administration of colistinmethanesulfonate has given encouraging results in pertussis, influenza, meningitis, urinary tract infections, gram-negative septicemias, and endocarditis when caused by sensitive organisms. The most potentially serious toxic effect is renal damage. [35,41]
7	Erythromycin	**In vitro:** Bacteriostatic. Active primarily against gram-positive bacteria, but a few gram-negative organisms, certain rickettsiae, and large viruses are also susceptible. Active against ***Entamoeba histolytica*** and ***Trichomonas vaginalis.*** **In vivo:** Good protection in infections produced by gram-positive organisms, large viruses, rickettsiae, oxyurids, and ***E. histolytica.*** Rapid increase in resistance noted. Cross-resistance to a varying degree with other macrolides. [13,18]	Effective in streptococcal, pneumococcal, and staphylococcal infections, especially those caused by strains resistant to penicillin. Useful in patients allergic to penicillin. Occasional use in ***Haemophilus*** infections, venereal diseases, pertussis, diphtheria, and amoebiasis. Usually administered by the oral route. Has a low order of toxicity, but gastrointestinal side effects limit high oral dosage. Jaundice has occasionally been observed. [13,18]
8	Griseofulvin	**In vitro:** An antifungal agent with no activity against bacteria. The majority of fungi are sensitive, including most human pathogens, notable exceptions being ***Candida albicans, Saccharomyces cerevisiae, Torulopsis utilis,*** and oomycetes. Mycostatic. **In vivo:** When administered orally, active in dogs and guinea pigs infected with ***Trichophyton rubrum*** and ***Microsporum canis.*** Presence of griseofulvin in hair shafts was demonstrated. [8,28]	Oral administration useful in the treatment of superficial infections of the hair, nails, and skin. Localizes and concentrates in these keratinized tissues. Cures may require long, continued dosage. Ineffective in deep mycoses. Very low toxicity, but occasional mild gastrointestinal upset, diarrhea, headache, and drug rashes may occur. [8,28,40]
9	Kanamycins	**In vitro:** Bactericidal. Active against most strains of staphylococci, ***Vibrio, Salmonella, Shigella,*** mycobacteria, coliforms, ***Proteus,*** and some strains of ***Pseudomonas.*** Inactive against streptococci, pneumococci, anaerobes, yeasts, and fungi. Some cross-resistance with paromomycin and neomycin, less cross-resistance with streptomycin. **In vivo:** Effective in protecting mice against ***Klebsiella pneumoniae, Diplococcus pneumoniae, Proteus vulgaris,*** and ***Staphylococcus aureus;*** no protection against virulent strains of ***Streptococcus pyogenes.*** Active against tuberculosis in guinea pigs. [17,22,58-60]	Useful in infections caused by staphylococci, ***Escherichia coli, Proteus, Klebsiella,*** and some strains of ***Pseudomonas.*** Therapy usually correlates well with sensitivity tests. Used orally to obtain preoperative sterilization of the bowel. Commonest parenteral administration is by the intramuscular route. Usefulness in tuberculosis is limited by rapid development of resistance and by ototoxicity. Other side effects include nephrotoxicity, eosinophilia, pain at site of injection, and rashes. The kanamycin in present use is primarily A, which is less toxic than B. [59,60]

continued

Part II. BIOLOGICAL ACTIVITY

	Antibiotic	Biological Activity	Clinical Results
	(A)	(B)	(C)
10	Neomycins	**In vitro:** Bactericidal. Active primarily against gram-positive cocci, gram-negative rods, acid-fast bacilli, and actinomycetes. More active against staphylococci than streptococci. Little or no activity against yeasts, filamentous fungi, viruses, or protozoa. **In vivo:** Protected mice and chick embryos from lethal doses of *Staphylococcus aureus* and *Salmonella typhosa;* effective in tuberculosis in guinea pigs, and in *Klebsiella pneumoniae, Proteus vulgaris, Pseudomonas aeruginosa,* and cholera infections in mice. [13,53,60]	Employed orally for preoperative bowel preparation, management of liver failure, and management of gastroenteritis due to *Escherichia coli.* A topical solution or ointment is used for superficial infections. Not used parenterally. Intraperitoneal or intrapleural injections may cause respiratory arrest or insufficiency. Ototoxic and nephrotoxic. Oral treatment may cause gastrointestinal distress. [13,53,60]
11	Novobiocin	**In vitro:** Bactericidal. Staphylococci, including strains resistant to other antibiotics, are uniformly susceptible. Streptococci, while generally sensitive, are more variable. Gram-negative bacteria, except for strains of *Haemophilus*, are generally insensitive. Activity reduced in presence of serum. Rapid induction of resistance. **In vivo:** Protected mice in acute and chronic staphylococcal infections, but less active than erythromycin in streptococcal and pneumococcal infections. Also active in mice against *Pasteurella multocida, Proteus vulgaris,* and *Haemophilus influenzae.* No activity in tuberculosis, or in fungal, rickettsial, and viral infections. [13]	Primary use in staphylococcal pyodermas insensitive to other antibiotics; some usefulness in pneumococcic pneumonia, undulant fever, and in genitourinary infections due to *Proteus, Staphylococcus aureus,* or *Streptococcus faecalis.* Calcium and sodium salts absorbed via the oral route (the route commonly used). Much patient-to-patient variation in serum binding; the dosage therefore is determined on an individual basis. Tendency for resistant strains to appear in clinical practice. Skin rash, urticaria, drug fever, and occasional leucopenia may be noted. Very high doses may induce liver damage. [13,37]
12	Nystatin	**In vitro:** Fungistatic and fungicidal. Active against most fungi, including *Candida albicans* and species of *Blastomyces, Coccidioides, Cryptococcus, Epidermophyton, Histoplasma, Microsporum,* and *Trichophyton.* Affects production of certain enzymes by sensitive organisms; also affects cell permeability. Has laboratory use in controlling yeast and mold contaminations in biological samples, culture media, tissue cultures, etc. **In vivo:** Protected mice infected with strains of *Candida* or *Histoplasma.* [13,20]	Effective against various forms of moniliasis when administered by the topical or oral routes, by inhalation, or by local injection. Frequently used prophylactically with broad spectrum antibacterial antibiotics. Oral use curtailed by poor absorption. Temporary gastric upset may occur with oral treatment, and severe toxicity with injection. [13,20]
13	Olcando-mycin	**In vitro:** Bacteriostatic. Mostly active against gram-positive bacteria. Gram-negative activity limited to *Haemophilus, Brucella,* and *Neisseria.* Cross-resistant with erythromycin and other macrolides. **In vivo:** Good therapeutic activity in mice against *Streptococcus pyogenes* and *Staphylococcus aureus.* [14,48]	Employed in infections caused by gram-positive cocci, especially in cases of penicillin sensitivity. Administered orally or intravenously. Triacetyloleandomycin has similar use and is pharmacologically superior, but is not suitable for parenteral injection because of low solubility. Toxicity is mostly confined to gastrointestinal distress. [14]
14	Paromo-mycin	**In vitro:** Bactericidal and bacteriostatic. Broad spectrum of activity against gram-positive and gram-negative organisms and mycobacteria. Moderate activity against *Vibrio comma,* nonmammalian mycobacteria, and *Shigella* spp. Inactive against *Pseudomonas aeruginosa.* **In vivo:** Especially effective against staphylococci and gram-negative bacilli in experimental mouse infections. Moderately tuberculostatic when given parenterally to mice and guinea pigs. Effective in amoebic infections in dogs and rats. [11,44]	Oral form is used for chronic and acute intestinal amoebiasis, enteric bacterial infections, preoperative bowel treatment, and management of hepatic coma. May exert a mild laxative side effect. Nephrotoxic when administered parenterally. [44,60]
	Penicillins		
15	Ampicil-lin	**In vitro:** Slightly less active than penicillin G against pyogenic cocci. Active against many gram-negative bacteria, including *Escherichia coli, Haemophilus influenzae, Salmonella* spp., *Shigella* spp.; *Proteus* activity varies with the	Efficacious in acute and chronic respiratory infections, in many urinary infections, and in peritonitis and wound infections. May be useful in cholecystitis, meningitis, and endocarditis, especially when caused by streptococci of

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94. ANTIBIOTICS

Part II. BIOLOGICAL ACTIVITY

	Antibiotic (A)	Biological Activity (B)	Clinical Results (C)
	Ampicillin (*See* preceding page)	strain. Inactive against ***Aerobacter aerogenes, Pseudomonas pyocyanea,*** and staphylococci resistant to penicillin G. **In vivo**: Stable in acid medium and well-absorbed orally. Active in animals against infections produced by sensitive organisms. [26,50]	group D. Use in infections from ***Proteus*** and coliforms should be governed by sensitivity tests. Can be given orally or intramuscularly. Nontoxic but is cross-allergenic with other penicillins. [50]
16	Benzylpenicillin (Penicillin G)	**In vitro**: Bactericidal. In general, highly active against gram-positive bacteria. Most strains of the following are sensitive to low concentrations: ***Bacillus, Clostridium, Corynebacterium, Diplococcus, Micrococcus, Streptococcus, Actinomyces, Borrelia, Leptospira,*** and ***Treponema.*** With the exception of ***Haemophilus*** and ***Neisseria,*** most gram-negative bacteria are not sensitive. Inactive against *Mycobacterium* spp., pleuropneumonia-like organisms, yeasts, fungi, viruses, rickettsiae, protozoa. Resistance develops in a slow, stepwise manner. Destroyed by penicillinase (organisms producing penicillinase are resistant). **In vivo**: Activity in experimental infections in general follows the "in vitro" antimicrobial spectrum. [5,12]	Drug of choice in infections caused by all strains and species of ***Streptococcus;*** pneumococci; nonpenicillinase-producing strains of staphylococci; gonococci; spirochetes, ***Borrelia,*** and spiral organisms of the mouth; clostridia; ***Corynebacterium***; and anthrax. Aqueous, crystalline penicillin G is used for rapid effect or high serum concentrations. For longer-lasting activity (e.g., in prophylaxis of rheumatic fever or glomerulonephritis), procaine (or benzathine) penicillin G is administered intramuscularly. Usefulness limited by allergenic reactions, sensitivity to penicillinase, and acid instability which precludes oral dosage. [5,30]
17	Cephalosporin N	**In vitro**: Bactericidal. Less active than other important penicillins against gram-positive bacteria, but shows good activity against many gram-negative bacteria, its activity against ***Salmonella*** being more than tenfold that of penicillin G. **In vivo**: Protected mice from infection with ***Salmonella typhimurium, S. typhosa, Escherichia coli, Proteus vulgaris,*** and ***P. mirabilis,*** and chicks with ***S. pullorum.*** Activity in vivo sometimes greater than is indicated by "in vitro" tests. [1]	Effective in limited trials in the treatment and control of typhoid fever in man. Has also been used for the treatment of gonorrhea and syphilis in patients sensitive to penicillin G. [1]
18	Methicillin	**In vitro**: Bactericidal. As active as penicillin G against penicillin-sensitive, or resistant, staphylococci. Less active against streptococci. **In vivo**: Activity corresponds to that indicated in "in vitro." [26]	Particularly useful in infections caused by penicillin-resistant staphylococci. Must be administered parenterally. Low toxicity, but shows complete cross-allergenicity with other penicillins. [26]
19	Oxacillin	**In vitro**: Activity resembles that of methicillin, but oxacillin is five-to-eight times more active against resistant staphylococci. **In vivo**: Resembles penicillin V in stability, absorption, and serum level, but oxacillin binds more readily to serum than any other available penicillin. [2,25]	As useful as methicillin in same types of infections, but oxacillin is resistant to acid and therefore is an effective oral antibiotic against resistant staphylococci. [2,25]
20	Phenethicillin	**In vitro**: Has spectrum similar to that of penicillin V. **In vivo**: As active as penicillin V against ***Diplococcus pneumoniae*** and ***Streptococcus pyogenes*** infections, and more active against ***Staphylococcus aureus*** infections. Not active against strains resistant to penicillin G. [16]	A penicillin capable of being administered orally. Its use parallels that of penicillin V, but phenethicillin is reported to give higher and more constant blood-level concentrations than does potassium penicillin V. [32]
21	Phenoxymethylpenicillin (Penicillin V)	**In vitro**: Spectrum of activity is the same as for penicillin G, but V is more stable at pH of less than 6.5. **In vivo**: Protection in pneumococcal and other infections equivalent to that produced by penicillin G. Acid stability permits good protection via the oral route. [7,9]	Range of activity in treating various infections is comparable to that of penicillin G.. Has the advantage of oral administration. [7,9]
22	Polymyxins	**In vitro**: Bactericidal. Active mainly against gram-negative bacteria, including ***Pseudomonas. Proteus*** strains are often resistant. Little or no activity against fungi. **In vivo**: Good protection in mice infected with	Used mainly in serious infections due to ***Pseudomonas aeruginosa,*** such as urinary tract infections and meningitis. Effective in gram-negative infections of body surfaces (eye, ear, skin wounds) and of body spaces (joint, pleural,

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94. ANTIBIOTICS

Part II. BIOLOGICAL ACTIVITY

	Antibiotic (A)	Biological Activity (B)	Clinical Results (C)
	Polymyxins (*See* preceding page)	*Salmonella typhosa, Bordetella pertussis,* and *Klebsiella pneumoniae,* and in chicks infected with *Pasteurella multocida* and *S. gallinarum.* No protection against streptococci and staphylococci. [13,23]	dural). Used topically or by mouth, as in *Salmonella enteritis.* Often combined with other drugs. Parenteral use may cause neuro- and nephro-toxicity, pain at site of injection, fever, and rashes. [13,23]
23	Ristocetins	**In vitro:** Bactericidal and bacteriostatic. Specifically active against gram-positive bacteria and mycobacteria; inactive against gram-negative bacteria (including *Haemophilus influenzae* and *Neisseria* spp.), yeasts, filamentous fungi, and protozoa. No cross-resistance with other antibiotics. **In vivo:** Controlled infections of mice caused by *Streptococcus pyogenes, Staphylococcus aureus,* and *Diplococcus pneumoniae.* Not effective against tuberculosis in mice. [19,39]	Most useful in severe staphylococcal and enterococcal infections resistant to other antimicrobials. Useful in short-term therapy of enterococcal endocarditis. Only administered intravenously. Toxicity is directly related to size of dosage and may include disturbances of the hematopoietic system, phlebitis, fever, and rash. [39]
24	Spiramycins	**In vitro:** Bacteriostatic. Especially active on gram-positive bacteria and to a lesser extent on mycobacteria and some gram-negative bacteria. Active on rickettsiae. Cross-resistance with other macrolides. **In vivo:** Protected mice infected with hemolytic streptococci, pneumococci, and staphylococci. Activity in vivo is greater than is indicated by "in vitro" tests. [13,36]	Active in various staphylococcal infections; particularly useful against organisms resistant to other antimicrobials. Promising results in gonococcal infections. Orally administered. Toxicities are very low or nonexistent. [13]
25	Streptomycin	**In vitro:** Bactericidal. Active against gram-positive and gram-negative bacteria, including mycobacteria. No activity against fungi, rickettsiae, or viruses. Rapid development of resistance. **In vivo:** Excellent protection in a wide variety of experimental infections, including *Bacillus anthracis, Brucella abortus, Diplococcus pneumoniae, Mycobacterium tuberculosis, Neisseria meningitidis, Pasteurella pestis, P. tularensis, Staphylococcus aureus, Streptococcus pyogenes,* and species of *Haemophilus, Klebsiella, Pseudomonas, Salmonella, Shigella.* [45,52]	Often combined with bacteriostatic agents, such as one of the tetracyclines or sulfonamides, chloramphenicol, etc. Is used alone or in combination against tuberculosis, *Haemophilus influenzae* meningitis, subacute bacterial endocarditis, tularemia, plague, *Klebsiella pneumoniae,* or *Escherichia coli* infections. Parenteral or topical application. Use in tuberculosis is limited by rapid development of resistant strains. May cause ototoxicity, but is less likely to do so than dihydrostreptomycin or a combination of the two. [45,52]
26	Streptovaricin	**In vitro:** The streptovaricin complex and components A, B, and C are very active against gram-positive bacteria and mycobacteria, and show activity against some gram-negative bacteria and fungi. Components D and E have only low activity against gram-positive bacteria. **In vivo:** Highly effective in the tuberculous mouse, component C being the most active. Effectiveness increased when combined with isoniazid. [29,38,46]	Only slight improvement in patients with advanced pulmonary tuberculosis when administered orally (50 mg/kg daily dosage). Some gastrointestinal upset observed. Results when combined with isoniazid were not superior to those with isoniazid alone, and were inferior to isoniazid-pyrazinamide treatment. [6,29]
27	Tetracyclines[1]	**In vitro:** Bacteriostatic. Broad spectrum of activity against gram-positive and gram-negative bacteria. Also active against coccidia, amoebae, and balanthidia. Superior to penicillin against *Bacillus anthracis.* Effective against rickettsiae and larger viruses. No activity against fungi. Resistance does not develop readily, but there is almost complete cross-resistance among the four major tetracyclines. **In vivo:** Good protection in laboratory animals against sensitive microorganisms in the groups listed under "in vitro." Little or no protection against *Mycobacterium tuberculosis.* No activity against small viruses or fungi. [8,10,27,33,49]	The commercially available tetracyclines are useful in infections caused by a wide range of microorganisms, including group A streptococci, staphylococci, pneumococci, meningococci, *Bacillus anthracis, Haemophilus influenzae, Bordetella pertussis, Entamoeba histolytica,* rickettsiae, and viruses of the lymphogranuloma-psittacosis group. Toxicity is very low and primarily confined to gastrointestinal upset, although a phototoxic reaction has been reported for demethylchlortetracycline. Dosage is usually via the oral route, although parenteral injection or topical application may be used as required. [8,10,27,33,49]

/1/ Chlortetracycline, demethylchlortetracycline, oxytetracycline, and tetracycline.

continued

Part II. BIOLOGICAL ACTIVITY

	Antibiotic (A)	Biological Activity (B)	Clinical Results (C)
28	Tyrothricin[a]	**In vitro:** Tyrothricin is a mixture of approximately 20% gramicidin (the active component) and 80% tyrocidine. It is bacteriostatic at low concentrations and bactericidal at high (1.0 µg/ml, or more). Active against corynebacteria, diplococci, staphylococci, streptococci, lactobacilli, and some fungi. **In vivo:** Tyrocidine loses most of its antibacterial activity in the presence of animal tissues, although it shows some effect against gram-negative cocci. Tyrothricin gives protection against pneumococci, streptococci, and staphylococci, but produces hemolysis and acute lethal toxicity upon injection. [55]	Tyrothricin is employed as a solution, spray, or in troches against sensitive gram-positive bacteria. Sometimes combined with bacitracin. The toxicity of the antibiotic precludes parenteral use. Since it is effective only when in direct contact with microorganisms, it is of little or no value in deep-seated infections. [55]
29	Vancomycin	**In vitro:** Bactericidal. Uniformly active against pathogenic staphylococci. Also inhibits hemolytic streptococci, pneumococci, enterococci, gonococci, corynebacteria, and clostridia. Not active against most gram-negative bacteria, mycobacteria, fungi, and yeasts. Unaffected by serum and by pH of the test medium. Resistance develops slowly, and there is no cross-resistance with other antibiotics. **In vivo:** Mice received complete protection from staphylococcal infections when vancomycin was injected subcutaneously. No protection against *Toxoplasma gondii*. [15,24,39]	Used primarily in severe staphylococcal infections: pneumonia and empyema, infections of skin and soft tissues, septicemia and endocarditis, osteomyelitis, and enterocolitis. Intravenous administration. Occasional phlebitis, chills, fever, renal irritation, urticaria, macular rashes, and hearing loss, but these side effects are less common with more highly purified preparations. Rare instances have been noted of cross-allergy with other antibiotics. [15,24,39]

/a/ Gramicidin and tyrocidine.

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95. ANTICOAGULANTS

Anticoagulant dosage is usually determined in vitro from the clotting time for heparin and heparinoid compounds, or the prothrombin time for indirect anticoagulants [5,20,21,27]. In vivo, the dosage required to prevent coagulation may be many times that indicated by the test in vitro [30].

Direct Anticoagulants: Heparin and heparinoid compounds injected intravenously give a prolonged coagulation time. For some purposes, the high peak blood levels resulting from intravenous administration are essential [26]. Heparin is inactive orally [13], and intramuscular and subcutaneous injections are not as generally effective as those given intravenously [32]. The subcutaneous route, however, is the commonly accepted method of choice in doses of 75-100 mg, given each 8-12 hours (depending on the clotting time) [32]. It is desirable that the clotting time be approximately twice that of the normal control before the next dose is administered [32]. The effect on clotting time is increased and prolonged by caronamide [29] and phosphorylated hesperidin [10]. Value for maximum clotting time can be estimated from the effect of clotting time in vitro [24]. International unit of heparin = 1/130 mg of the international standard; commercial heparin = 90-120 units/mg.

Indirect Anticoagulants: These drugs usually are given orally. Dosage is dependent on the technique used to detect the change in prothrombin time and on individual susceptibility to the drug. A number of individuals in various species are refractory to one or more of these drugs, as judged by the effect on prothrombin time [25]. Significantly different results are obtained with tests for coagulation factors. The action of these drugs is cumulative and can be greatly enhanced by following the initial dose with a series of smaller doses. Such administration also avoids toxic side effects. Dicumarol must be dissolved with a small amount of 5*N* sodium hydroxide for intravenous use. It can be given intraperitoneally in suspension in propylene glycol (10-100 mg/ml). Warfarin and tromexan are more soluble than dicumarol and can be given intraperitoneally in neutral solution.

Route (column B): iv = intravenous; im = intramuscular; ip = intraperitoneal; sc = subcutaneous; rec = rectal; po = oral. Values in parentheses are ranges, estimate "b" (cf. Introduction).

	Species (Common Name)	Dose and Route	Maximum Clotting Time or Prothrombin Time		Achievement of Therapeutic Effect	Recovery Time	Remarks	Reference
			Control	Experimental				
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
				Heparin[1,2]				
1	*Homo sapiens* (man)	1,000 units (10 mg); iv	....	<4.5 min	....	....	28 hyporeactors	9
2			....	4.5-7 min	....	....	50 normal reactors	
3			....	>7 min	....	....	7 hyperreactors	

/1/ Intra-arterial injection of 1 mg heparin/100 ml of blood, plus 1.2 mg protamine/100 ml of blood into venous outflow of organ (limb, kidney), gives satisfactory local heparinization (without general heparinization) in man and dog [15]. /2/ To neutralize heparin in man and dog, slowly inject protamine in the amount of 1.2-2.5 x weight of heparin in blood, as determined by in vitro titration; excess of protamine will be anticoagulant [7,15,22].

continued

95. ANTICOAGULANTS

	Species (Common Name)	Dose and Route	Maximum Clotting Time or Prothrombin Time		Achievement of Therapeutic Effect	Recovery Time	Remarks	Reference
			Control	Experimental				
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Heparin[1,2]							
4	*Homo sapiens* (man)	5,000 units; iv	15 min	115 min	...	...	...	9
5		150 mg; iv	...	>80 min	...	4 hr	Incoagulable for 1 hr	26
6		100 mg; iv	...	>80 min	...	4 hr	Incoagulable for ½ hr	
7		75 mg; iv	...	80 min	...	4 hr	...	
8		50 mg; iv	...	55 min	...	2 hr	...	
9		150 mg; im	12 min	30 min	...	10 hr	...	
10		100 mg; im	12 min	27 min	...	6 hr	...	
11		25, 50, 75 mg; im	12 min	18 min	1 hr	3-4 hr	...	
12	*Canis familiaris* (dog)	30 units/kg; iv	...	34 min	...	32 min	...	24
13		100 units/kg; iv	...	>2 hr	...	...	...	
14		450 units/kg; sc	...	0.25-3.5 hr	...	2-13 hr	Prolonged by anesthetics	20
15		2-3 units/kg/min for 2 hr; iv	20 sec	5 min	...	4 hr	Thrombin time used; heparin appeared in lymph in 10-90 min	31
16		65-290 units/kg; iv	20 sec	5 min	...	200 min		
17	*Rattus norvegicus* (Norway rat)	1,950 units/kg; sc	...	>24 hr	...	6 hr	Normal in 12 hr	22
18		5,500 units/kg; sc	...	>24 hr	...	12 hr	Normal in 18 hr	
19	*Oryctolagus cuniculus* (European rabbit)	10.5 mg/kg[3] (50 units/kg)	...	...	...	100 min	Duration proportional to dose	16
20		2.5 mg/kg	...	>60 min	...	2 hr	...	3
21		1.0 mg/kg	...	40 min	...	1 hr	...	
	Dextran Sulfate							
22	*Oryctolagus cuniculus* (European rabbit)	21 mg/kg	...	>80 min	...	3 hr	...	3
23		17 mg/kg	...	>80 min	...	100 hr	...	
24		7 mg/kg	...	>80 min	...	50 min	...	
	Thrombocid (Xylan Polysulfuric Acid)							
25	*Oryctolagus cuniculus* (European rabbit)	30 mg/kg	...	>60 min	...	2.5 hr	...	3
26		15 mg/kg	...	65 min	...	1.5 hr	...	
	Dicumarol (3, 3'-Methylene-bis-4-hydroxycoumarin)							
27	*Homo sapiens* (man)	300 mg	...	...	...	...	Minimum effective dose	1
28		250 mg	...	30 sec	...	...	...	19
29		500 mg	...	63 sec	3-4 da	Varies	...	
30		750 mg	...	106 sec	...	...	...	
31	*Canis familiaris* (dog)	5 mg/kg	10.7(6.7-14.7) sec	37.8(30.4-45.2) sec	...	6 da	Quick prothrombin time	25
32	*Mesocricetus auratus* (golden hamster)	5 mg/kg	...	No effect	...	...	Effective only with vitamin K deficient diet	25
33	*Mus musculus* (house mouse)	5 mg/kg	10.6(7.8-13.4) sec	14.0(12.4-15.6) sec	...	24 hr	Quick prothrombin time	25
34	*Rattus norvegicus* (Norway rat)	5 mg/kg	14.0(11.4-16.6) sec	19.9(18.7-21.1) sec	...	24 hr	Quick prothrombin time	25
35	*Oryctolagus cuniculus* (European rabbit)	5 mg/kg	8.0(7.6-8.4) sec	25.4(8.4->60) sec	...	10 da	Quick prothrombin time	25
36		2.5 mg	8.0(7.6-8.4) sec	10.6(6.2-15.0) sec	...	5 da		
37		10 mg/kg	15-16 sec	27 sec	1 da	4 da	Susceptibility decreased in puerperium	19
38		25 mg/kg	15-16 sec	80 sec	1 da	5 da		
39		50 mg/kg	15-16 sec	6.5 min	2.5 da	8 da		
40		100 mg/kg	15-16 sec	20 min	3 da	8 da		
41		0.37 mg	28 sec	32 sec	1 da	3 da	Susceptible animals only; 12.5% plasma prothrombin time	28
42		0.75 mg	28 sec	40 sec	1⅔ da	4⅔ da		
43		1.5 mg	28 sec	46 sec	2 da	8 da		

/1/ Intra-arterial injection of 1 mg heparin/100 ml of blood, plus 1.2 mg protamine/100 ml of blood into venous outflow of organ (limb, kidney), gives satisfactory local heparinization (without general heparinization) in man and dog [15]. /2/ To neutralize heparin in man and dog, slowly inject protamine in the amount of 1.2-2.5 x weight of heparin in blood, as determined by in vitro titration; excess of protamine will be anticoagulant [7,15,22]. /3/ Crude heparin.

continued

95. ANTICOAGULANTS

	Species (Common Name)	Dose and Route	Maximum Clotting Time or Prothrombin Time		Achievement of Therapeutic Effect	Recovery Time	Remarks	Reference
			Control	Experimental				
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Dicumarol (3, 3'-Methylene-bis-4-hydroxycoumarin)							
44	*Oryctolagus cuniculus* (European rabbit)	3 mg	28 sec	67 sec	2.5 da	9 da	Susceptible animals only; 12.5% plasma prothrombin time	28
45		6 mg	28 sec	85 sec	3 da	10 da		
46	*Gallus domesticus* (chicken)	100 mg/kg	...	...	...	...	Minimum effective dose	27
47		300 mg/kg	...	...	...	...	Effective dose	
	Tromexan (3, 3'-Carboxymethylene-bis-4-hydroxycoumarin)							
48	*Homo sapiens* (man)	1,200 mg	14 sec	25 sec	30 hr	56 hr	...	6
49		1,200 mg	14 sec	32 sec	30 hr	60 hr	...	
50	*Canis familiaris* (dog)	10 mg/kg	15 sec	40 sec	2 da	5 da	...	17
51		40 mg/kg	15 sec	55 sec	3 da	5 da	...	
52	*Oryctolagus cuniculus* (European rabbit)	400 mg	12 sec	30 sec	30 hr	48 hr	...	6
53	*Gallus domesticus* (chicken)	100-500 mg/kg	...	...	...	...	Minimum effective dose	27
	Warfarin (3-[α-Acetonylbenzyl]-4-hydroxycoumarin)							
54	*Homo sapiens* (man)	45-50 mg initial	12 sec	28 sec	...	...	5-10 mg/da for maintenance	8, 32
55		100 mg; rec	...	40 sec	18-24 hr	6 da	...	14
56	*Rattus norvegicus* (Norway rat)	0.03 mg/kg/da	25-36 sec	No effect	...	...	...	2
57		0.05 mg/kg/da	25-36 sec	55 sec	...	...	...	
58		0.10 mg/kg/da	25-36 sec	2 min	...	...	...	
59	*Oryctolagus cuniculus* (European rabbit)	40 mg/kg; ip	9.6 sec	36.7 sec	48 hr	...	...	18
60		5 mg/kg; ip	7.9 sec	35.2 sec	48 hr	...	...	
	Liquamar (3-[1'-Phenylpropyl]-4-hydroxycoumarin)							
61	*Homo sapiens* (man)	18 mg	20.9 sec	40 sec	96 hr	144 hr	...	4
62		21 mg	20.9 sec	36 sec	96 hr	168 hr	Minimum effective dose	4, 27
63	*Oryctolagus cuniculus* (European rabbit)	2.5 mg	14 sec	22 sec	48 hr	96 hr	...	4
64		4 mg	14 sec	22 sec	72 hr	160 hr	...	
65	*Gallus domesticus* (chicken)	50 mg/kg	...	...	...	...	Minimum effective dose	27
	EDC (Ethylidene-bis-4-hydroxycoumarin)							
66	*Homo sapiens* (man)	0.5 g	...	Great individual variation	...	...	0.2 g maintenance dose	11
67	*Oryctolagus cuniculus* (European rabbit)	20 mg; po	7 sec	10 sec	...	...	...	11
68		30 mg; po	7 sec	27 sec	...	...	...	
	Phenindione (2-Phenyl-1, 3-indanedione)							
69	*Canis familiaris* (dog)	50 mg/kg	9-13 sec	30 sec	26 hr	36 hr	...	23
70	*Oryctolagus cuniculus* (European rabbit)	50 mg/kg	10-12 sec	22 sec	25 hr	40 hr	...	23
	Dipaxin (2-Diphenylacetyl-1, 3-indanedione)							
71	*Homo sapiens* (man)	20 mg	...	...	1-2 da	6-10 da	2-4 mg maintenance dose	12

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96. ANIMAL

Part I.

For information on standardization of methods of extraction, preparation, and purification of venoms, consult
alinase; *E* = cholinesterase; *F* = deoxyribonuclease; *G* = diaminoxidase; *H* = diastase; *I* = dipeptidase; *J* = endopep-
P = lipase; *Q* = 5-nucleotidase; *R* = ophio-adenosine triphosphatase; *S* = phosphatase; *T* = phospholipase; *U* = phos-
enzyme activity known not to be present.

	Species (Common Name)	Distribution	Adult Length ft	Fibrinogen[1]		Prothrombin[1]		Enzyme Activity[2]	Mouse Toxicity[3] mg/kg
				Coagulate	Destroy	Activate	Destroy		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
	Crotalidae[4]								
1	*Ancistrodon contortrix* (southern U.S. copperhead)	Eastern and southern United States	2-3½					$\cancel{E}$,*N*,*U*, $\cancel{V}$,*X*	LD_{50} 25.6 LD_{100} 53.0
2	*A. piscivorus* (eastern cottonmouth)	Southeastern United States to central Texas	3-5	-	+	-	+	*D*,$\cancel{E}$,*K*,*L*, *N*,*O*,*Q*, *T*,*U*,$\cancel{V}$,*X*	LD_{50} 25.8 LD_{100} 45.0
3	*Bothrops atrox* (fer-de-lance)	Central Mexico to eastern Argentina, Martinique, Tobago, Trinidad, & St. Lucia	4½-6½	+	-	-	+	$\cancel{E}$, *F*,*N*,*R*, *X*	LD_{50} 62.8-99.2
4	*B. jararaca* (jararaca)	Brazil to northern Argentina & Paraguay	3½-4½	+	-	+	-	*A*,$\cancel{E}$, *J*,*L*, *N*,*R*,*X*	LD_{50} 2.0-22.6
5	*Crotalus adamanteus* (eastern diamondback rattlesnake)	Southeastern United States, in lowlands	4½-6½	+	+	-	-	*D*,$\cancel{E}$,*L*,*N*, *Q*,*U*,$\cancel{V}$,*X*	LD_{50} 14.5
6	*C. atrox* (western diamondback rattlesnake)	Southwestern United States, northern Mexico	3½-5½	-	+	-	-	*A*,$\cancel{E}$,*L*,*N*, *R*,*X*	LD_{50} 7.5 LD_{100} 19.0
7	*C. durissus terrificus* (cascabel)	Southern Mexico to Uruguay & Argentina, mostly in highlands	4-5½	+	-	±	-	$\cancel{E}$,*F*,*L*,*N*, *O*,*R*,*X*	LD_{50} 0.6 LD_{50} 0.1 (intravenous)
8	*C. viridis* (prairie rattlesnake)	Western United States, southwestern Canada, northern Mexico	2½-5					$\cancel{E}$,*N*	LD_{50} 7.2
9	*Lachesis muta* (bushmaster)	Costa Rica to northern S. America	8-11					*X*	LD_{100} 57.0
10	*Sistrurus catenatus* (eastern massasauga)	Southern Ontario, central to southwestern United States	2-3					$\cancel{E}$,*N*,*R*	LD_{50} 5.2 LD_{100} 9.0

/1/ Information from reference 23, unless otherwise specified in column M. /2/ Presence in venom determined by
unless otherwise stated. /4/ Fangs front, movable, hollow; pit between eye and nostril; more than 80 species.

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reference 17. **Enzyme Activity** (column H): *A* = bradykininogen; *B* = carboxypolypeptidase; *C* = catalase; *D* = cephtidase; *K* = flavin adenine dinucleotide; *L* = hyaluronidase; *M* = invertase; *N* = L-amino-acid oxidase; *O* = lecithinase; phodiesterase; *V* = phosphomonoesterase; *W* = polypeptidase; *X* = protease. Slash mark (/) through letter indicates

Symptoms of Envenomation in Man (J)	Mortality % (K)	Available Antiserum (L)	Reference (M)	
Crotalidae[4]				
Local pain, swelling and necrosis; lymphangitis and lymphadenitis; sweating, nausea, vomiting. Severe cases: shock, petechiae, bloody stools.	<1	Yes	H,40,43,74,114;I,68;J,12,15,84	1
Similar to poisoning by *A. contortrix*, but more severe; local necrosis more marked.	2-10	Yes	H,19,23,26,40,41,43,74,91,92,114;I,68;J,54,84,99	2
Local pain, edema and lymphadenopathy; bleeding from fang punctures, gums, nose and other body orifices; low prothrombin, prolonged clotting time; moderate to high leukocytosis; hematuria. Severe cases: shock, failure of pupils to react to light, respiration irregular. Autopsy: hemorrhagic necrosis at site of bite; hemorrhages into muscles, bowel, central nervous system; blood incoagulable.	10-20	Yes	H,7,23,43,101,114,116,118;I,86;J,49	3
Similar to poisoning by *B. atrox*. Autopsy: generalized visceral hemorrhages, cerebral hemorrhage, hemoglobinuric nephrosis.	5-15	Yes	H,7,23,27,42,43,67,100,109,114,116;I,87,88;J,68	4
Local pain, edema and ecchymoses; dryness of mouth, vomiting, shock, hemolytic anemia. Severe cases: muscular twitching, paresthesia, cyanosis, afibrogenemia, anemia, proteinuria, blood in feces, speech difficulty, sensation of yellow vision, unconsciousness.	5-15	Yes	H,21-23,40,41,43-45,93,114,117;I,55,68;J,2,55,61,108	5
Similar to poisoning by *C. adamanteus*, but neurotic symptoms less marked. Severe cases: profound shock.	5-15	Yes	H,23,24,64,109,114,116,117;I,55,68,84;J,25,55	6
Similar to poisoning by *Naja naja*, except that no edema occurs.	>40	Yes	H,17,23,27,36,63,101,114,116,117;I,68,86;J,16,68	7
Usual local symptoms of *Crotalus* poisoning; also thirst, abdominal pain, vomiting, diarrhea, dyspnea. Severe cases: excitement, hypertonicity of muscles, paresthesia, convulsions, cyanosis, respiratory failure, clouding of consciousness, weakness, and sweating.	1-2	Yes	H,114;I,68;J,8,20,25,55,81	8
Inadequate information. Rapid death preceded by severe, shocklike state.	Usually 100	Yes	H,7;I,84;J,68	9
Pain, edema, ecchymoses; weakness, sweating, vomiting. Severe cases: hemolytic anemia.	1-5	Yes	H,114,116;I,55,68,84;J,55,59	10

characteristic activity, rather than by specific isolation, of enzyme. /3/ Dry venom administered subcutaneously,

continued

	Species (Common Name)	Distribution	Adult Length ft	Fibrinogen[1]		Prothrombin[1]		Enzyme Activity[2]	Mouse Toxicity[3] mg/kg
				Coagulate	Destroy	Activate	Destroy		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
	Crotalidae[4]								
11	*Trimeresurus mucrosquamatus* (Taiwan habu)	Southeastern China, Formosa	3-4						MLD 7.6
	Viperidae[5]								
12	*Bitis arietans* (puff adder)	Africa, southern Arabia	$2\frac{1}{2}$-5	-	+	-	-	*A,E,N,R, U,V,X*	MLD 7.5
13	*Echis carinatus* (saw-scaled viper)	India, Iraq, Arabia, Africa (north of equator)	$1\frac{1}{2}$-$2\frac{1}{2}$	+				*B,E,I,J, L,N,R, W,X*	LD_{50} 3.3
14	*Vipera berus* (European viper)	British Isles, across northern Europe and Asia to Japan	$1\frac{1}{2}$-$2\frac{1}{2}$					*A,N*	Mean LD 6.5
15	*V. russelli* (Russell's viper)	India, Burma, southern China, Formosa, Java	4-$5\frac{1}{2}$	+	-	-	+	*B,E,H,I, J,K,L, M,N,O, P,Q,R,T, U,V,W,X*	MLD 1.0 LD_{50} 5.0
	Hydrophidae[6]								
16	*Enhydrina schistosa* (beaked sea snake)	Persian Gulf to S. China Sea, and south to Ceylon & northern Australia; mostly coastal waters	3-$3\frac{1}{2}$	-	-	-	-	*O*	MLD 0.05-0.13
	Elapidae[7]								
17	*Acanthophis antarcticus* (death adder)	Most of Australia (excluding Tasmania), New Guinea, nearby islands	$1\frac{3}{4}$-3	+?		+?		*E,L,N,O, R,T*	LD_{100} 0.5
18	*Bungarus candidus caeruleus* (Indian krait)	India, Burma, Malay Peninsula, Java, Sumatra, Celebes	$3\frac{1}{2}$-$4\frac{1}{2}$					*E,K,N,X*	LD_{50} 1.0 LD_{100} 3.0
19	*Demansia textilis* (brown snake)	Most of Australia (excluding Tasmania)	$4\frac{1}{2}$-7					*E,N,R,T*	LD_{100} 0.25
20	*Dendroaspis angusticeps* (eastern green mamba)	Eastern Africa, Ethiopia to Natal	6-13					*E,N,R*	LD_{50} 3.5
21	*Denisonia superba* (Australian copperhead)	Southeastern Australia	$3\frac{1}{2}$-5	+?		+?		*E,L,N,O, R,T*	LD_{100} 1.2
22	*Hemachatus haemachates* (ringhals)	S. Africa	3-4	+	-	±	-	*E,N,O,Q, R,U,V,X*	Mean LD 1.5
23	*Micrurus corallinus* (coral snake)	Subtropical S. America	2-4					E,L,N,R	
24	*M. fulvius* (eastern coral snake)	Southern United States to northeastern Mexico	2-$3\frac{1}{2}$						LD (MLD?) 1.0
25	*Naja naja* (Indian cobra)	Southern Asia to Indonesia, Formosa, Philippines	4-6	-	-	-	+	*B,E,H,I, J,L,M, N,O,P, R,U,V, W,X*	MLD 0.75 LD_{50} 0.20

/1/ Information from reference 23, unless otherwise specified in column M. /2/ Presence in venom determined by unless otherwise stated. /4/ Fangs front, movable, hollow; pit between eye and nostril; more than 80 species. mately 50 species, strictly marine. /7/ Fangs front, grooved though virtually fused for most of length; more than

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Symptoms of Envenomation in Man (J)	Mortality % (K)	Available Antiserum (L)	Reference (M)	
Crotalidae[4]				
Local pain, ecchymoses, blistering; little systemic reaction.	2-10	Yes	I,57;J,95,111	11
Viperidae[5]				
Severe local edema, necrosis and sloughing; restlessness, weak pulse, dyspnea, gastrointestinal hemorrhages.	11-40	Yes	H,23,40,109,114,116; I,38;J,39,90	12
Local pain and edema; ecchymoses and hemorrhages from mucous membranes and into viscera; profound anemia, abdominal pain, impaired liver function; prothrombin time greatly prolonged, thrombocytopenia. Autopsy: intestinal and retroperitoneal hemorrhage.	11-40	Yes	D,58;H,27,33,34,36, 56,114,115;I,68;J, 69,82;L,39	13
Local pain and edema of bitten extremity, sometimes extending into trunk; hemorrhages along lymphatics. Little systemic reaction; sometimes vomiting, sweating, abdominal pain, faintness, cyanosis, shock. Ptosis common after bite by *V. berus bosniensis*.	1-5	Yes	H,109,119;I,85;J,75, 83,98,102,106	14
Rapidly spreading edema with extravasation of blood, epistaxis and petechiae, abdominal pain, vomiting, paralytic ileus, collapse, shock, albuminuria, prolonged clotting time. Terminally: loss of consciousness, failure of pupils to react to light, circulatory failure. Autopsy: subcutaneous hemorrhages near site of bite, meningeal congestion, blood in lungs.	11-40	Yes	H,19,23,33-36,40,41, 44,45,60,74,79,80, 91,114,116;I,57,77; J,13,112	15
Hydrophidae[6]				
No local reaction; latent period minutes to few hours. Giddiness, muscular aching followed by muscle weakness, ptosis, trismus, hypertension. Death from respiratory failure, cardiac arrest, or acute renal failure. Autopsy: marked, widespread myonecrosis; renal congestion with distal tubular necrosis.	12-25	Yes	D-H,10;I,9,68;J,K, 66,78	16
Elapidae[7]				
Similar to poisoning by *Notechis scutatus* except that peripheral circulatory failure is more common and hemorrhagic phenomena occur.	11-40	Yes	D,F,104;H,19,28,111, 114,116;I,71;J,53	17
Little pain or local reaction. Latent period may extend to 12 hours, followed by abdominal pain, staggering gait, dysphagia, dyspnea, ptosis, stiffness of jaws, coma, respiratory paralysis, cardiac failure.	77	Yes	H,48,74,91,114;I,48, 77;J,1,31	18
Latent period to 12 hours, followed by abdominal pain, vomiting, headache, dizziness, weakness, rapid pulse and subnormal temperature, respiratory and circulatory collapse, hemoglobinuria, and peripheral thromboses.	11-40	Yes	H,19,114,116;I,52;J, 53	19
Local pain and swelling, salivation, paralysis of vocal cords, sweating, vomiting, restlessness, drowsiness or collapse followed by coma; dyspnea and respiratory failure.	>40	Yes	H,114,116;I,14;J,76	20
Similar to poisoning by *Notechis scutatus*. Rapid loss of muscle tone and consciousness, peripheral circulatory failure.	11-40	Yes	D,F,104;H,11,19,28, 103,114,116;I,50; J,53	21
Pain; dyspnea; weak, thready pulse; cyanosis; collapse. Venom sprayed at eyes; effects resemble those produced by *Naja nigricollis*.	2-10	Yes	H,5,23,40,114,116;I, 85;J,29,90	22
Numbness without pain at bite. Early symptoms: headache, swelling of face and lips; hyperesthesia, sore throat, ptosis, photophobia, normal pupillary reflex, vomiting, cramps, dyspnea, loss of muscle tone, tachycardia. Later symptoms: backache, irritability, salivation, brachycardia, dysuria, albuminuria.	11-40	Yes	H,114-117;J,113	23
Cyclic pains radiating from site of bite; somnolence, dyspnea, dysphagia, sweating; soreness of face, throat, and eyes.	5-20	No	I,62;J,110	24
Pain radiating from site of bite; edema, numbness, tremors, ptosis, drooping of head, salivation, speech difficulty, giddiness, muscular incoordination and weakness, blindness, progressive depression of respiration, convulsions, incontinence of urine and feces. Pupils react to light, and heart continues to beat, after respiration has ceased.	11-40	Yes	H,3,6,23,30,32-34, 36,40,46,65,72-74, 79,80,94,114,117; I,77;J,1,13,31	25

characteristic activity, rather than by specific isolation, of enzyme. /3/ Dry venom administered subcutaneously. /5/ Fangs front, movable, hollow; approximately 50 species. /6/ Fangs short, front, permanently erect; approxi- 150 species.

continued

	Species (Common Name)	Distribution	Adult Length ft	Fibrinogen[1]		Pro-thrombin[1]		Enzyme Activity[2]	Mouse Toxicity[3] mg/kg
				Coag-ulate	De-stroy	Acti-vate	De-stroy		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
	Elapidae[7]								
26	*Naja nigricollis* (black-necked cobra)	Africa (south of Sahara in savanna area)	5-6				+	*E,N,R,T, X*	MLD 2.5
27	*Notechis scutatus* (tiger snake)	Most of Australia except northern part	$3\frac{1}{2}$-6	-	-	+	-	*E,L,N,R, S,T,U, V,X*	LD_{50} (guinea pig) 6.5 µg/kg LD_{100} 0.3
28	*Ophiophagus hannah* (king cobra)	Western India, Burma, Philippines, Indonesia, southern China, Thailand	12-16					*E,N,R*	
29	*Oxyuranus scutellatus* (taipan)	Northern Australia, New Guinea	6-11	+?		+?		*O,T*	LD_{100} 0.17
30	*Pseudochis porphyriacus* (Australian black snake)	Eastern & southern Australia	4-$6\frac{1}{2}$	+?		+?		*N,O,T*	LD_{100} 3.5
	Colubridae[8]								
31	*Dispholidus typus* (boom-slang)	Africa, forested portions (south of Sahara)	$4\frac{1}{2}$-$5\frac{1}{2}$			+?		*X*	MLD 10.0
	Helodermatidae								
32	*Heloderma suspectum* (Gila monster)	Southwestern United States (chiefly Arizona), north-western Mexico (chiefly Sonora)	$1\frac{1}{2}$-2						LD_{50} (rat), 20.18 (lyo-philized venom)

/1/ Information from reference 23, unless otherwise indicated in column M. /2/ Presence in venom determined by unless otherwise stated. /7/ Fangs front, grooved though virtually fused for most of length; more than 150 species. /8/ Antiserum for crotalid envenomation believed to be effective.

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Symptoms of Envenomation in Man	Mortality %	Available Antiserum	Reference	
(J)	(K)	(L)	(M)	
Elapidae[7]				
Similar to poisoning by *N. naja*. Venom frequently sprayed at eyes; contact produces acute, intense ophthalmia. Systemic poisoning does not occur from such contact, and permanent damage to vision is rare.	11-40	Yes	G,47;H,19,74,114,116;I,38;J,68	26
Latent period 15-60 minutes, followed by nausea, vomiting, faintness, drowsiness, sweating. Later symptoms: dullness of sensation, staggering, dysphagia, slurred speech, ptosis, dilation of pupils and failure to react to light; rapid, weak pulse and respiration; progressive dyspnea and death from respiratory failure.	>40	Yes	H,11,18,19,23,40,114,116;I,71,105;J,53	27
Similar to poisoning by *Naja* species. Symptoms develop rapidly; death often occurs in 30-60 minutes.	>40	Yes	H,114,116;J,107	28
Similar to poisoning by *Notechis scutatus*. Flaccid paralysis of limbs, intercostal and bulbar paralysis; often rapidly fatal.	>40	Yes	D,F,104;H,19,28,103;I,70;J,4	29
Local pain and swelling, vomiting, hemorrhages from nose and mouth, prostration, hematuria.	<1	Yes	D,F,104;H,19,28,103,114;I,51;J,53	30
Colubridae[8]				
Local pain, swelling and hemorrhage; ecchymoses, defibrination syndrome, bleeding from nose and mouth, sometimes from all mucous membranes and skin; headache, vomiting, collapse; temperature normal or subnormal.	High	Yes	F,H,I,37;J,37,96	31
Helodermatidae				
Local pain, swelling, hyperemia, weakness, hyperpnea, tinnitus, nausea, vomiting. Death from respiratory paralysis and cardiac failure.	<1->40	No[9]	I,97;J,89	32

characteristic activity, rather than by specific isolation, of enzyme. /3/ Dry venom administered subcutaneously, /8/ Numerous species, mostly harmless; fangs rear, immovable, grooved in venomous species; dangerous if handled.

and Morgan, F. G., (e) Christensen, P. Agerholm, (f) do Amaral, Afranio

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	Toad	Distribution	Bufagins[1]			Bufotoxins[2]
			Name (Proposed Formula)	Action or Effect[4]	Toxicity[5] mg/kg	Name (Proposed Formula)
	(A)	(B)	(C)	(D)	(E)	(F)
1	*Bufo alvarius* (Colorado River toad)	Southwestern United States				Alvarobufotoxin
2	*B. americanus* (American toad)	Eastern United States	Americobufagin	Digitalis-like action		Americobufotoxin
3	*B. arenarum* (sand toad)	Argentina	Arenobufagin ($C_{25}H_{34}O_6$)	Digitalis-like action; emesis; systolic standstill	0.092 ±0.005	Arenobufotoxin ($C_{39}H_{60}O_{11}N_{14}$)
4	*B. bufo* (European toad)	Europe				Vulgarobufotoxin ($C_{38}H_{60}O_{11}N_4$)
5	*B. formosus* (Japanese toad)	Japan	Gamabufagin ($C_{27}H_{38}O_6$)	Digitalis-like action; emesis; ventricular fibrillation	0.101 ±0.005	Gamabufotoxin ($C_{41}H_6O_{11}N_4$)
6	*B. woodhousii fowleri* (Fowler's toad)	Southeastern United States	Fowlerobufagin ($C_{23}H_{33}O_6$)	Digitalis-like action; emesis; ventricular fibrillation	0.218 ±0.012	Fowlerobufotoxin
7	*B. gargarizans* (Cantor's toad)	China	Cinobufagin ($C_{25}H_{31}O_5$)[9]	Digitalis-like action on vagus, vagus center, myocardium; emesis; clonic or tonic convulsions after paralysis	0.219 ±0.011	Cinobufotoxin ($C_{43}H_{64}O_{12}N_4$) or ($C_{39}H_{58}O_{11}N_4$)
			Telecinobufagin ($C_{24}H_{34}O_5$)		0.102 ±0.007	
8	*B. marinus* (marine toad)	Circumtropical	Marinobufagin[10] ($C_{24}H_{32}O_5$)	Digitalis-like action; emesis; ventricular fibrillation	0.555 ±0.028	Marinobufotoxin ($C_{38}H_{58}O_{10}N_4$) or ($C_{42}H_{62}O_{11}N_4$)[11]
9	*B. quercicus* (oak toad)	Southeastern United States	Quercicobufagin ($C_{23}H_{34}O_5$)	Digitalis-like action; emesis; ventricular fibrillation	0.097 ±0.004	Quercicobufotoxin

/1/ Bufagins are steroid-type compounds [1, 8, 20, 32]. /2/ Bufotoxins are the conjugation product of the specific molecule [13]. /4/ On cat, guinea pig, rabbit, pigeon, frog. /5/ Average fatal dose for cat (intravenous) [2]. /9/ On [12]. /10/ Also reported as occurring in *B. Paracnemis* (Argentina) [18, 34, 35]. /11/ Also reported as $C_{42}H_{64}O_{11}N_4$

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TOADS

Bufotoxins[2]		Bufotenines[3]			Other Compounds Isolated	Reference	
Action or Effect[6]	Toxicity[5] mg/kg	Name (Proposed Formula)	Action or Effect[7]	Cardiac Arrest[8]			
(G)	(H)	(I)	(J)	(K)	(L)	(M)	
Digitalis-like action; emesis; systolic standstill	0.756 ±0.075	Alvarobufotenine ($C_{12}H_{18}O_2N_2$)	Oxytocic; slight pressor action; diastolic standstill	1:5,000 dilution	Cholesterol, ergosterol	6,8,13	1
Digitalis-like action	--	Americobufotenine ($C_{12}H_{18}O_2N_2$)	Oxytocic; marked pressor action			6,9,13	2
Digitalis-like action; emesis; ventricular fibrillation	0.406 ±0.012	Arenobufotenine A ($C_{12}H_{20}O_3N_2$) Arenobufotenine B ($C_{14}H_{18}O_2N_2$)	Oxytocic; slight pressor action	1:5,000 dilution	Cholesterol, epinephrine	8,13,15	3
Emesis; ventricular fibrillation	0.292 ±0.017	Vulgarobufotenine ($C_{12}H_{18}O_2N_2$)	Oxytocic; marked pressor action		Cholesterol, ergosterol	7,8,13, 14	4
Persistent action; slight pressor action; emesis; ventricular fibrillation	0.374 ±0.027	Gamabufotenine ($C_{12}H_{18}O_2N_2$)	Oxytocic; marked pressor action	1:5,000 dilution	Cholesterol, epinephrine, bufotenedine	8,13,16, 17,22, 33	5
Emesis	0.792 ±0.054	Fowlerobufotenine ($C_{13}H_{20}O_2N_2$)	Oxytocic; marked pressor action; epinephrine-like action	1:5,000 dilution	Bufotenedine	6,8,13, 22,33	6
Emesis; vasopressor effect, followed by cardiac collapse, death in systole; prolongation of P-R interval	0.359 ±0.024	Cinobufotenine ($C_{12}H_{16}ON_2$)	Oxytocic; miotic; intense, short vasopressor action; contraction of smooth muscle not inhibited by atropine	1:10,000 dilution	Cholesterol, epinephrine, norepinephrine, bufotenedine	3,6,7, 11-13, 22-31	7
More emetic than bufagin	0.417[12] ±0.022	Marinobufotenine ($C_{12}H_{14}O_2N_2$)	Oxytocic; no pressor action	1:5,000 dilution	Epinephrine, cholesterol, ergosterol, 5-hydroxytryptamine	1,5-7, 10,13, 19	8
Ventricular systolic standstill		Quercicobufotenine ($C_{12}H_{18}O_2N_2$)	Oxytocic; slight pressor action		Cholesterol?	6,13	9

bufagin with one molecule of suberyl-arginine [8]. /3/ Bufotenines are organic bases having an indole ring in the cat, pigeon, frog. /7/ On cat, guinea pig, frog. /8/ Frog, heart perfusion method. /9/ Also reported as $C_{29}H_{38}O_7$ [21]. /12/ Also reported as 0.43 [5] and 0.49 [10].

continued

	Toad	Distribution	Bufagins[1] Name (Proposed Formula)	Bufagins[1] Action or Effect[4]	Bufagins[1] Toxicity[5] mg/kg	Bufotoxins[2] Name (Proposed Formula)
	(A)	(B)	(C)	(D)	(E)	(F)
10	*Bufo regularis* (leopard toad)	South Africa	Regularobufagin ($C_{23}H_{34}O_5$)	Digitalis-like action; emesis; ventricular fibrillation	0.153 ±0.006	Regularobufotoxin ($C_{37}H_{60}O_{10}N_4$)
11	*B. valliceps* (Mexican toad)	Eastern Mexico, Texas & Louisiana	Vallicepobufagin ($C_{23}H_{34}O_5$)	Nausea; emesis; A-V block, and ventricular standstill	0.201 ±0.017	Vallicepobufotoxin
12	*B. viridis* (green toad)	Europe	Viridobufagin ($C_{23}H_{34}O_5$)	Nausea; emesis; increased intestinal tone; ventricular fibrillation	0.111 ±0.008	Viridobufotoxin ($C_{37}H_{60}O_{10}N_4$)

/1/ Bufagins are steroid-type compounds [1, 8, 20, 32]. /2/ Bufotoxins are the conjugation product of the specific molecule [13]. /4/ On cat, guinea pig, rabbit, pigeon, frog. /5/ Average fatal dose for cat (intravenous) [2]. /6/ On 10.7 mg per animal.

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Part III. MARINE ORGANISMS

Chordata

1 CATFISH STING, caused by contact with spine located in front of the soft-rayed portion of the dorsal and pectoral fins.

Species & Distribution: *Bagre marina* (sea catfish); Cape Cod to Brazil
Clarias batrachus (catfish); India to Indonesia, Philippines
Galeichthys felis (sea catfish); Cape Cod to Gulf of Mexico
Heteropneustes fossilis (catfish); India, Ceylon, Vietnam
Plotosus lineatus (sea catfish); vicinity of river mouths in Indo-Pacific area

Symptoms: Instant stinging pain, usually localized. Primary shock. Pallor about wound, occasionally some edema. Rarely serious. [12, 20, 57, 64, 106-108]

2 CIGUATERA POISONING, caused by ingestion of any one of a number of species of fishes, the flesh of which becomes toxic under certain conditions.

Species & Distribution: *Acanthurus glaucopareius* (surgeonfish); tropical Pacific, Indonesia, Philippines
A. triostegus (Indo-Pacific convict fish); Hawaiian & Johnson Islands
Albula vulpes (ladyfish); warm seas
Alutera scripta (longtail filefish); warm seas
Aprion virescens (blue-gray snapper); tropical Indo-Pacific
Balistoides niger (triggerfish); tropical Pacifio, China, Japan
Caranx hippos (jack); tropical Atlantic
Cephalopholis argus (blue-spotted argus); tropical Indo-Pacific
Clupanodon thrissa (gizzard shad); tropical Pacific, Japan, China, Formosa, Korea, Indonesia, India
Engraulis japonica (anchovy); China, Japan, Korea, Formosa
Epibolus insidiator (Indo-Pacific long-jawed wrasse); tropical Indo-Pacific
Epinephelus fuscoguttatus (mottled grouper); Indo-Pacific

continued

Bufotoxins[2]		Bufotenines[3]			Other Compounds Isolated	Reference	
Action or Effect[6]	Toxicity[5] mg/kg	Name (Proposed Formula)	Action or Effect[7]	Cardiac Arrest[8]			
(G)	(H)	(I)	(J)	(K)	(L)	(M)	
Emesis; ventricular fibrillation	0.477 ±0.026	Regularobufotenine	Oxytocic; marked pressor action		Epinephrine[13]	4,8,13	10
		Vallicepobufotenine ($C_{11}H_{12}O_2N_2$)	Oxytocic; slight pressor action; decreased amplitude and arrest of heart contractions	1:1,000 dilution		6,13	11
Action similar to, but weaker than, that of viridobufagin	0.270 ±0.012	Viridobufotenine A ($C_{12}H_{18}O_2N_2$)	Oxytocic; marked pressor action	1:5,000 dilution	Cholesterol, ergosterol	8,13,16	12
		Viridobufotenine B ($C_{12}H_{20}O_3N_2$)	Oxytocic; slight pressor action				

bufagin with one molecule of suberyl-arginine [8]. /3/ Bufotenines are organic bases having an indole ring in the cat, pigeon, frog. /7/ On cat, guinea pig, frog. /8/ Frog, heart perfusion method. /13/ 4.3-5.0% of whole venom,

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Part III. MARINE ORGANISMS

Chordata
Gnathodentex aureolineatus (snapper); Tuamotu Archipelago west to eastern Africa
Katsuwonus pelamis (skipjack); circumtropical
Lactophrys trigonus (trunkfish); Atlantic coast of tropical America north to Cape Cod
Lactoria cornutus (trunkfish); tropical Pacific
Lethrinus miniatus (snapper-like fish); Polynesia west to eastern Africa
Lutjanus bohar (twinspot snapper); tropical Pacific to eastern Africa, Red Sea
L. gibbus (red snapper); tropical Indo-Pacific
L. monostigma (one-spot snapper); Polynesia west to Red Sea, China
L. vaigiensis (red snapper); Polynesia west to eastern Africa, Japan
Mycteroperca venenosa (sea bass); western tropical Atlantic
Pagellus erythrinus (porgy); Mediterranean & Black Seas, eastern Atlantic from British Isles & Scandinavia to Azores, Canary Islands, Fernando Po
Pagrus pagrus (porgy); E. Atlantic, Mediterranean
Paradicichthys venenatus (Chinaman fish); Australia
Parupeneus chryserydros (surmullet); Polynesia west to eastern Africa
Plectropomus oligacanthus (sea bass); Indonesia, Philippines, Caroline & Marshall Islands
Scarus caeruleus (blue parrot fish); Florida, W. Indies
S. microrhinos (parrot fish); Indo-Pacific
Sphyraena barracuda (great barracuda); Indo-Pacific, Hawaii to Red Sea, western Atlantic from Brazil to W. Indies, Florida, Bermuda
Tetragonurus cuvieri (squaretail); temperate waters
Upeneus arge (surmullet); Polynesia, Micronesia

continued

96. ANIMAL TOXINS

Part III. MARINE ORGANISMS

Chordata

CIGUATERA POISONING *(See* preceding page)

Symptoms: Onset within 36 hours; tingling about the lips, tongue, and throat, followed by numbness of some parts. Dryness of mouth, nausea, vomiting, and abdominal cramps common. Headache, dizziness, pallor, restlessness, weakness, blurring of vision, itching, ataxia, and convulsions may occur. Deaths reported.

Chemistry: Heat-stable; soluble in some organ solutions, but reported insoluble in water; dialyzable. [3, 6, 57, 59, 69, 79, 105, 110, 130]

3 GYMNOTHORAX POISONING, caused by ingestion of any of several species of fishes, the flesh of which becomes toxic under certain conditions.

Species & Distribution: *Gymnothorax flavimarginatus* (moray eel); Hawaiian Islands west to eastern Africa
G. javanicus (moray eel); Hawaiian Islands west to eastern Africa
G. meleagris (white-spotted moray eel); Hawaiian Islands west to eastern Africa, Japan south to Australia
G. pictus (speckled moray eel); Polynesia to eastern Africa
G. undulatus (brown moray eel); Hawaiian Islands to Red Sea & eastern Africa

Symptoms: Tingling and numbness about lips, tongue, throat, hands, and feet; feeling of heaviness in the legs. Nausea, vomiting, abdominal cramps, joint pains, difficulty in swallowing and breathing, weakness, ataxia, and convulsions may occur. Deaths reported.

Chemistry & Toxicology: Small molecular substance. Death in mice produced by 1 ml (ip). [57, 66, 104]

4 SCORPION-FISH STING, caused by contact with dorsal, pelvic, or anal spines. Venoms produced by venom glands differ in three genera: *Pterois, Scorpaena,* and *Synanceja.*

Species & Distribution: *Apistus carinatus* (scorpion fish); coasts of India, Indonesia, Philippines, China, Japan, Australia
Centropogon australis (waspfish); coasts of New South Wales, Queensland
Choridactylus multibarbis (stonefish); coasts of India, Philippines, Polynesia
Inimicus didactylus (lumpfish); Philippines, Malaya
I. japonicus (stonefish); coasts of Japan
Minous monodactylus (stonefish); coasts of Japan, China, S. Pacific Islands
Notesthes robusta (scorpion fish); coasts of New South Wales, Queensland
Pterois antennata (thread-finned zebra fish); tropical & temperate seas
P. lunulata (tiger fish); coasts of Japan, Banka Islands
P. volitans (turkey fish); Red Sea, Indian Ocean, Melanesia, Micronesia, Polynesia, coasts of China, Japan, Australia
Scorpaena guttata (California scorpion fish); central California coast to Gulf of California
S. plumieri (sculpin); Atlantic coast of N. America to Brazil
S. porcus (hogfish); Atlantic coast of Europe from English Channel to Canary Islands, Mediterranean & Black Seas
Scorpaenopis diabolus (scorpion fish); coasts of Indonesia, Australia, Melanesia, Polynesia
Synanceja horrida (poison stonefish); coasts of India, E. Indies, China, Philippines, Australia
S. verrucosa (poison stonefish); Red Sea, coasts of Africa, India, & Australia, tropical Indo-Pacific

Symptoms: Immediate, severe, localized pain; pallor about wound, and sometimes symptoms of primary shock. Later manifestations include severe pain and weakness of involved extremity, dyspnea, headache, nausea, and vomiting. Coma and deaths reported.

Chemistry & Toxicology: Several proteins with lethal effect in one band, as separated on gel electrophoresis. LD_{50} = 200 µg protein/kg. Produces hypotension similar to that caused by stingray and weever-fish venoms. No adrenergic-blocking action. [8, 13, 29, 56, 57, 60-62, 97, 98, 120, 124, 128, 138]

5 STINGRAY STING, caused by contact with bilaterally serrated, dentinal caudal spine or sting. Venom contained within ventrolateral grooves of sting, enveloped in an integumentary sheath.

Species & Distribution: *Aetobatus narinari* (spotted duck-billed ray); tropical & warm-temperate areas of Atlantic, Pacific, & Indo-Pacific oceans, Red Sea
Dasyatis dipterurus (diamond stingray); coast of British Columbia to Central America
D. pastinaca (stingray); northeastern Atlantic & Indian Oceans, Mediterranean & Red Seas
Gymnura marmorata (butterfly stingray); coast of California to Mexico
Myliobatis californicus (bat stingray); coast of Oregon to Lower California
Potamotrygon motoro (freshwater stingray); rivers of Paraguay, Amazon south to Rio de Janeiro
Urolophus halleri (round stingray); southern Pacific coast of N. America

Symptoms: Immediate, intense, localized pain, with increased skin temperature and discoloration or pallor about wound. Often symptoms of primary shock. Lacerated-type wound with ragged edges, some edema. Nausea, vomiting, headache, weakness, sweating, cramps, and diarrhea reported. Death extremely rare.

Chemistry & Toxicology: Several soluble protein fractions of low-to-average molecular weight, extremely labile and rapidly inactivated on heating. LD_{50} of crude extract = 15 mg/kg. Small doses produce vasodilation; large doses, vasoconstriction. Direct effect on the heart, but not on the central nervous system or neuromuscular junction. [7, 52, 58, 111-113, 115-119]

6 TETRAODON POISONING, caused by ingestion of any of a number of species of puffers, the flesh of which may become toxic under certain conditions. Toxicity thought to be related to food-chain habits. Liver, gonads, intestines, and skin most toxic.

Species & Distribution: *Arothron hispidus* (puffer); tropical Pacific to Japan & Red Sea
A. meleagris (white-spotted puffer); west coast of Central America to Indonesia
A. nigropunctatus (black-spotted puffer); Polynesia, Indo-Pacific, Japan to eastern Africa & Red Sea

continued

Chordata

Canthigaster margaritatus (sharp-nosed puffer); Red Sea, eastern Africa, Indonesia, China
C. rivulatus (sharp-nosed puffer); Japan, Hawaiian Islands
Chilomycterus spinosus (spiny boxfish); W. Indies, Brazil, S. Africa
Colomesus psittacus (freshwater puffer); rivers of Guiana, northern Brazil, W. Indies
Diodon holacanthus (balloonfish); tropical Atlantic, Pacific, & Indian Oceans
Fugu basilevskianus (puffer); northern China, northwestern Korea
F. chrysops (puffer); Pacific coast of central Japan
F. niphobles (puffer); Japan
F. ocellatus (puffer); China, Japan, Philippines
F. pardalis (puffer); China, Japan
F. pseudomus (puffer); E. China & Yellow Seas
F. rubripes (puffer); China to Korea, Sea of Japan, Pacific
F. stictonotus (puffer); southern Korea, E. China Sea, Japan
F. vermicularis (puffer); E. China Sea, Japan
F. xanthopterus (puffer); China, Korea, southern Japan
Lagocephalus laevigatus inermis (smooth puffer); eastern Africa, tropical Indian Ocean, Australia, E. China Sea, southern Japan
L. lunaris (smooth puffer); Red Sea, southern & eastern Africa, India to Australia, China, Japan
L. sceleratus (smooth puffer); east coast of Africa to Philippines, southern Japan, Australia, Tahiti
Mola mola (common ocean sunfish); temperate & tropical seas
Sphaeroides annulatus (bull's-eye puffer); Baja California to Peru, Galapagos Islands
S. maculatus (northern puffer); Atlantic coast of N. America to Guiana
S. spengleri (bandtail puffer); coasts of Texas, Florida, W. Indies, Brazil, Canary Islands, west coast of Africa
Tetraodon lineatus (puffer); rivers of Africa
Torquigener hamiltoni (puffer); Australia, Melanesia, Polynesia

Symptoms: Onset within 10-50 minutes, with tingling and numbness about mouth, lips and tongue, excessive salivation, weakness, nausea, vomiting, and difficulty in swallowing. Paresthesia and paralysis may occur over different parts of the body; convulsions and coma reported. Mortality rate about 50%.

Chemistry & Toxicology: Suggested formula, $C_{16}H_{31}NO_{16}$; soluble; LD_{50} = approximately 10 µg/kg. Direct effect on neuromuscular transmission and on nerve and muscle without depolarization. Affects heart contractile force. Causes ascending-type paralysis in laboratory animals. [10, 36, 45, 46, 57, 65, 73, 77, 90, 131, 139-142]

7 TOADFISH STING, caused by contact with opercular or dorsal spines. Venom produced in gland at base of spines.

Species & Distribution: *Batrachus cirrhosus* (toadfish); Red Sea
B. didactylus (paddefisk); Mediterranean Sea & nearby Atlantic coasts
B. grunniens (toadfish); coasts of Malaya, Burma, India, Ceylon
Opsanus tau (oyster toadfish); Atlantic coast of United States
Thalassophryne reticulata (venomous toadfish); Pacific coast of S. America

Symptoms: Onset immediate, with local pain, tenderness, increased skin temperature, and sometimes primary shock. Nausea and occasionally vomiting. Pain spreads throughout affected part; some swelling and redness about the wound. Few systemic effects; rarely serious. [9, 35, 42, 43, 49, 53, 57, 135]

8 TURTLE POISONING, caused by ingestion of any one of several species of marine turtles, the flesh of which becomes toxic under certain conditions. Rare.

Species & Distribution: *Chelonia mydas* (green sea turtle); tropical & subtropical seas
Dermochelys coriacea (leatherback sea turtle); circumtropical, occasionally found in tropical waters
Eretmochelys imbricata (hawksbill sea turtle); tropical & subtropical seas

Symptoms: Onset within 1-24 hours, with nausea, vomiting, severe abdominal cramps, increased salivation, difficulty in swallowing, and subsequent paresthesia about mouth, lips, tongue, and throat; diarrhea and tendency toward somnolence. Coma and deaths reported. [18, 57, 129]

9 WEEVER-FISH STING, caused by contact with opercular or dorsal spines or stings. Spines covered by integumentary sheath; venom-producing cells within grooves of spine.

Species & Distribution: *Trachinus araneus* (weever); Mediterranean Sea
T. draco (greater weever); Norway to N. Africa, Mediterranean & Adriatic Seas
T. radiatus (weever); Mediterranean Sea
T. vipera (lesser weever); southern North Sea, English Channel & Mediterranean Sea

Symptoms: Immediate, intense, localized pain, increasing in severity and spreading within an hour to entire extremity. Occasionally symptoms of primary shock. Increased skin temperature about wound, some edema, and localized discoloration or pallor. Puncture-type wound; necrosis reported in some cases. Weakness, headache, nausea, vomiting, and muscle fasciculations also reported.

Chemistry & Toxicology: Toxin is a "muco" substance of a combined polysaccharide-protein nature. Also contains noradrenaline, adrenaline, histamine, cholinesterase, and a trace of 5-hydroxytryptamine. Free of sulfur, lecithinase, and phosphodiesterase. Direct effect on the heart, but no effect on the central nervous system or neuromuscular junction. Little hemotoxic or anticoagulant activity. [2, 13, 14, 32, 33, 50, 54, 102, 114]

continued

Part III. MARINE ORGANISMS

Echinodermata

10 SEA-CUCUMBER POISONING, caused by contact.

Species & Distribution: *Euapta lappa* (sea cucumber); Bahamas
Holothuria argus (sea cucumber); Torres Strait, Pacific, Palau Islands
H. atra (sea cucumber); Guam, Palau Islands, Pacific
H. tubulosa (sea cucumber); Mediterranean
Leptosynapta ooplax (sea cucumber); Japan
Paracaudina chilensis (sea cucumber); Japan, colder seas off coasts of N. & S. America
Stichopus variegatus (curry fish); Palau Islands, Pacific
Thelenota ananas (prickly red fish); Palau Islands, Japan

Symptoms: Localized pain, inflammation, tenderness

Chemistry & Toxicology: Holothurin A ($C_{50-52}H_{81-85}O_{5-6}SNa$), a steroid saponin, is comparable as a blocking agent to procaine and physostigmine on desheathed sciatic nerve of frogs, except that the action is irreversible. Produces irreversible block of direct and indirect twitch response, along with contracture, in mammalian nerve-muscle preparation. [15, 17, 23, 40, 41, 91-93, 96, 121]

11 SEA-URCHIN STING, caused by contact with spines or globiferous pedicellariae of any of several species of sea urchins.

Species & Distribution: *Asthenosoma ijimai* (sea urchin); southern Japan to Molucca Sea
Diadema setosum (reef urchin); Indo-Pacific from eastern Africa to Polynesia, China, Japan. Related species in W. Indies, Hawaiian Islands.
Toxopneustes elegans (sea urchin); Japan
T. pileolus (sea urchin); Indo-Pacific from eastern Africa to Melanesia, Japan

Symptoms: Immediate, localized pain; some redness about wound and aching in injured part. In more severe cases, primary shock, muscular paralysis, and respiratory distress may occur. Death rare.

Chemistry & Toxicology: Heat-stable; curare-like activity. [13, 21, 22, 28, 44, 89, 100, 127, 132]

Annelida

12 WORM BITE, caused by bite or stinging setae.

Species & Distribution: *Eurythoe complanata* (bristle worm); Gulf of Mexico, tropical Pacific
Glycera dibranchiata (bloodworm); Canadian coast to N. Carolina
Lumbriconereis heteropoda (marine worm); Japan

Symptoms: Pain similar to that caused by beesting; some localized edema, increased skin temperature, redness, and itching.

Chemistry & Toxicology: A tertiary amine; suggested formula, $C_5H_{11}NS_2$. Stimulates parasympathetic activity. Direct effect on the heart and nervous system. [57, 68, 75, 94, 95]

Mollusca

13 CONE STING, caused by contact with venom apparatus consisting of a bulb, duct, radular sheath, and radular teeth.

Species & Distribution: *Conus aulicus* (court cone); Polynesia to Indian Ocean
C. geographus (geography cone); Indo-Pacific from eastern Africa to Polynesia
C. striatus (striated cone); Indo-Pacific from eastern Africa to Australia
C. textile (textile cone); Polynesia to Red Sea
C. tulipa (tulip cone); Polynesia to Red Sea

Symptoms: Immediate, localized pain; ischemia, and sometimes numbness about puncture wound. Tingling or paresthesia about injured part; may spread. Muscular incoordination, paresis or paralysis, and visual disturbances reported. Deaths reported within 3-5 hours.

Chemistry & Toxicology: Toxin contains a protein, quaternary ammonium compounds, and possibly amines. Produces hyperexcitability, ataxia, dyspnea, respiratory distress in mice; paralysis in fishes and mammals. [1, 19, 24, 25, 30, 37-72, 76, 126, 137]

14 OCTOPUS BITE. Venom apparatus consists of anterior and posterior salivary glands, salivary ducts, buccal mass, and mandibles or beak.

Species & Distribution: *Octopus apollyon* (octopus); Pacific coast of N. America
O. macropus (octopus); Europe, Mediterranean and Red Seas, Indian Ocean, Malaysia, coasts of China, Japan, Australia
O. vulgaris (octopus); warm seas

Symptoms: Burning or tingling about wound punctures. Pain spreads to involve entire extremity. Wound bleeds freely. Some increased skin temperature; local redness and edema reported.

Chemistry & Toxicology: Composed of octopamine, serotonin, serotonin decomposition product, histamine, dopamine, and other substances. Anticoagulant and cardiotoxic activity; no cholinesterase or aminoxidase activity. [4, 5, 11, 47, 55, 57, 67, 82]

15 PARALYTIC SHELLFISH POISONING, caused by ingestion of mollusks which have fed upon toxic dinoflagellates.

Species & Distribution: *Cardium edule* (cockle); European seas
Donax serra (white mussel); South Africa
Ensis directus (razor clam); New England coast to Florida
Modiolus modiolus (horse mussel); Pacific coast of N. America from Arctic to Baja California; circumboreal.

continued

Part III. MARINE ORGANISMS

Mollusca

Mya arenaria (soft shell clam); coasts of Britain, Scandinavia, Greenland, Japan, Atlantic & Pacific coasts of N. America
Mytilus californianus (ocean mussel); eastern Alaska south to Socorro Island
M. edulis (mussel); Arctic to S. Carolina, Alaska to Baja California; found in most temperate waters
Saxidomus giganteus (butter clam); Alaska to central California
S. nuttalli (butter clam); northern California to Baja California
Schizothaerus nuttalli (gaper clam); Alaska to Baja California; northern coast of Japan
Spisula solidissima (surf clam); Labrador to N. Carolina

Symptoms: *See* entry 21.
Chemistry & Toxicology: *See* entry 21. [16, 31, 39, 48, 51, 57, 83, 85-87, 90, 122, 123, 125]

Cnidaria

16 HYDROID STING, caused by contact with nematocysts.
Species & Distribution: *Millepora alcicornis* (stinging coral); tropical Pacific, Indian Ocean, Caribbean & Red Seas
Symptoms: Burning sensation, itching, localized redness, occasional pustules and desquamation.
Chemistry & Toxicology: *See* entry 18. [15, 71, 103, 134, 136]

17 JELLYFISH STING, caused by contact with nematocysts located for the most part on the tentacles.
Species & Distribution: *Carybdea alta* (sea wasp); tropical Pacific, Atlantic, & Indian Oceans
Chiropsalmus quadrigatus (sea wasp); northern Australia, Philippines, Indian Ocean
Cyanea capillata (giant jellyfish); N. Atlantic & N. Pacific Oceans, New England to Arctic Ocean, France to northern Russia, Baltic Sea; Alaska to Puget Sound, Japan and China
Dactylometra quinquecirrha (pink-fringed jellyfish); Azores & New England to the tropics, W. Africa. Indian Ocean, western Pacific Ocean, Malaya to Japan & Philippines
Symptoms: Burning sensation with itching, localized edema and redness
Chemistry & Toxicology: (*See also* entry 18.) Medusocongestin present in some animals. Slow-reacting, histamine-liberating substance. Toxin hypersensitizes temperature perception organ. [34, 38, 57, 70, 74, 81, 101, 133]

18 PHYSALIA STING, caused by contact with nematocysts.
Species & Distribution: *Physalia physalis* (Portuguese man-o'-war); tropical Atlantic. Related species in Indo-Pacific, Hawaii, southern Japan.
Symptoms: Burning, localized pain; itching, edema, redness; erythematous wheals and paresthesia in some cases. Gastrointestinal symptoms, muscular weakness, and contractures in more severe cases. Respiratory distress and secondary shock may develop. Fatal cases reported.
Chemistry & Toxicology: Toxin contains several quaternary ammonium compounds, the most toxic being tetramine. Serotonin and histamine present; also histamine releasers and possibly several peptides; LD_{99} = approximately 2.2 mg/kg. [38, 71, 78, 80, 84, 100, 101, 103]

19 SEA-ANEMONE STING, caused by contact with nematocysts.
Species & Distribution: *Actinia equina* (sea anemone); E. Atlantic from Arctic to Gulf of Guinea, Mediterranean & Black Seas, Sea of Azov
Adamsia palliata (cloak anemone); Norway to Spain; Mediterranean Sea
Anemonia sulcata (sea anemone); E. Atlantic from Norway & Scotland to the Canary Islands; Mediterranean Sea
Sagartia elegans (sea anemone); Iceland to Atlantic coast of France, Mediterranean Sea, coast of Africa
Symptoms: Stinging sensation on contact; may be followed by itching, localized edema, and redness. Papules develop in severe cases. Death very rare. "Sponge fisherman's disease" attributed to *Sagartia*.
Chemistry & Toxicology: Toxin composed of several substances, including congestin and thalassin. Congestin is water-soluble, heat-resistant, and produces vomiting, diarrhea, and visceral congestion. Thalassin is a water-soluble, alcohol-precipitated crystal, antagonistic to congestin. Scratching and sneezing in dogs caused by 100 μg. Tetramine also present. [15, 23, 74, 99, 100, 109, 136, 143]

Porifera

20 SPONGE STING, caused by contact.
Species & Distribution: *Fibulia nolitangere* (brown sponge); W. Indies
Tedania ignis (fire sponge); W. Indies
T. toxicalis (fire sponge); California coast
Symptoms: Burning sensation, itching, urticaria, and occasionally localized edema.
Toxicology: Intraperitoneal injections of crude extracts lethal to mice [27, 63]. Kills aquarium animals [26].

Protozoa

21 PARALYTIC SHELLFISH POISONING, caused by ingestion of mollusks which have fed on toxic dinoflagellates. (*See also* entry 15.)
Species & Distribution: *Gonyaulax catenella* (dinoflagellate); Pacific coast of United States
G. polygramma (dinoflagellate); Japan, S. Africa
G. tamarensis (dinoflagellate); Atlantic coast of N. America
Gymnodinium brevis (dinoflagellate); Florida coast
Pyrodinium phoneus (dinoflagellate); North Sea

continued

Part III. MARINE ORGANISMS

Protozoa

PARALYTIC SHELLFISH POISONING (*See* preceding page)

Symptoms: Onset within 10 minutes to 4 hours, with weakness, thirst, and numbness about lips, mouth, tongue, and fingertips; followed by muscular incoordination, progressive paralysis (ascending type), and respiratory failure. Death may occur within 2-24 hours.

Chemistry & Toxicology: Basic substance forms salt with mineral acids. Optical rotation of 130°, with no absorption in ultraviolet. Formula, $C_{10}H_{17}N_7O_4 \cdot 2HCl$; molecular weight, 372. Direct effect on heart and myoneural junction. One of most potent toxins known, approximately 3 mg fatal to humans. [51, 83, 86, 88, 90, 122, 123, 125]

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97. PLANT TOXINS

	Plant (Common Name); Toxic Portion; Distribution	Toxic Principle	Signs and Symptoms Produced	Remarks
	(A)	(B)	(C)	(D)
1	*Abrus precatorius* (rosary pea); seeds, possibly root; southern Florida & tropics	Abrin (*N*-methyltryptophane) and abric acid [49]	Onset may be delayed several hours to two days; vomiting, diarrhea, acute gastroenteritis, chills, sometimes convulsions [34]. Severe cases: death from heart failure [49].	Two ounces of seed fatal to horse; one seed chewed may be fatal to child [49]. Boiled seeds may be eaten, but in quantity cause headache [10].
2	*Aconitum napellus* (aconite monkshood); roots, leaves, flowers, seeds; northeastern United States, Canada, Europe, Asia [23]	Principally aconitine, aconine, napelline; eight other alkaloids reported [51]	Tingling, burning sensation in tongue, throat, skin; great restlessness, dyspnea, slow pulse, muscular weakness, incoordination, cold and livid skin, pupillary constriction, followed by dilation [44]; vomiting, diarrhea, convulsions, possibly death in 1-8 hours by respiratory or cardiac paralysis [17].	Young leaves mistakenly eaten for parsley, and the roots for horseradish. Considered most dangerous of all British plants [17].
3	*Agrostemma githago* (corn cockle); seeds; United States, Canada, Europe [34]	Githagin, agrostemmic acid (saponins) [34,49]	Man: vertigo, diarrhea, depressed breathing [34]; irritation of digestive tract, vomiting, headache, sharp pains in spine, difficult locomotion, sometimes coma and death [8]. Horses, cattle: colic, diarrhea, muscular tremors, rigidity, coma, death [9].	Milled seeds sometimes in wheat flour [17]; frequent ingestion of small amounts results in chronic githagism [34]; 0.25-1 lb/100 lb live wt fatal to stock [34].
4	*Amanita phalloides* (death cup); entire fungus; N. America, Europe, E. Indies, Australia	Phalloidin [17]; *Amanita* hemolysin possibly a factor in poisoning when mushroom is eaten raw [16]	After 6-15 hours, abdominal pain [17]; vomiting, diarrhea, intense thirst, recurrent drowsiness [23,28]; respiratory and circulatory depression, delirium, and sometimes convulsions [40]; jaundice, hepatitis and renal disturbances, coma, death from heart failure.	One of the most deadly fungi, mortality about 50%; cause of majority of "mushroom deaths" in U.S. [17,40,44]. Genus contains other equally poisonous, and some edible, species [21].
5	*Antiaris toxicaria* (upas tree); milky sap; southern Asia, E. Indies [40]	Antiarin (α-, β-) [7]	Skin irritation, blistering, swelling [37]; vomiting, convulsions, death [7].	One of the principal arrow poisons; more potent than digitalis [7,40]. Cloth made from bark causes severe itching if sap not completely removed [7].
6	*Astragalus* spp. (locoweed); fresh plant; northern hemisphere [34]	Selenium; locoine in some species [34]	Horses, cattle: dullness, weakness, irregularity in behavior, impaired vision, edema of eyelids, loss of muscular control, depraved appetite, emaciation, starvation, death. Sheep: same symptoms as above and possibly blindness [34].	Hazard to livestock industry in U.S.; toxicity varies with locality [8]; some species harmless.

continued

	Plant (Common Name); Toxic Portion; Distribution	Toxic Principle	Signs and Symptoms Produced	Remarks
	(A)	(B)	(C)	(D)
7	*Atropa belladonna* (belladonna); entire plant, especially seeds, roots, leaves; eastern United States, Europe, Asia [34]	Chiefly hyoscyamine; atropine and hyoscine in small amounts [17]; six other alkaloids reported [51]	Man, acute: dryness of skin, mouth, throat [10]; difficulty in swallowing, flushing of face, cyanosis, mydriasis, nausea, vomiting, constipation, slurred speech, giddiness, stupor, coma, rapid and weak pulse, fever, death from asphyxia and heart failure [23]. Chronic: erythema, urticaria, vesicular eruptions, slurred speech, mydriasis, glaucoma, muscular tremors or twitchings; sudden withdrawal causes nausea, salivation, perspiration [6]. Cattle: mydriasis, constipation, rapid pulse, labored breathing, frenzy, paralysis [23].	Cultivated as source of the drug belladonna [35]. Children and grazing animals often poisoned by eating fruit of plant. Flesh of rabbits which have fed on plant is toxic to humans [17].
8	*Cannabis sativa* (hemp); upper leaves, flower bracts of female plants; United States, Mexico, tropical America, Europe, temperate Asia [34]	Cannabinol and cannabidiol, the latter isomerized to highly active tetrahydrocannabinol [47]	Man: exaltation, inebriety, confusion, followed by central nervous system depression. Prolonged addiction may produce dullness or mania [20,45]; large quantities may result in death from cardiac depression [10].	Dried leaves and bracts smoked by drug addicts; seeds harmless [34,49]. Used in "bird seed"; yields hemp seed oil for paints, etc.; plant stem yields hemp fiber for cordage, carpets, etc.
9	*Cicuta* spp. (water hemlock; primarily roots; leaves, stems less toxic; northern temperate regions [17,34]	Cicutoxin [34]	Man, other animals: abdominal pain, nausea, vomiting, diarrhea, mydriasis, labored breathing, foaming at mouth, weak and rapid pulse, epileptoid convulsions, death from respiratory failure [17, 34].	Genus includes the most poisonous plants in U.S. Fatalities have resulted from mistaking roots for parsnips [17,34].
10	*Claviceps purpurea* (ergot claviceps); sclerotium; N. America, Europe, Asia, Australia[35]	Ergotoxine, ergotamine, ergonovine, ergometrine [18]	Man, acute: vomiting, diarrhea, respiratory difficulties, visual and motor disturbances followed by convulsions, lowered blood pressure, shallow respiration, unconsciousness. In pregnancy, possibly uterine hemorrhage, abortion, peripheral gangrene. Chronic, convulsive type: vomiting, itching, paresthesia, analgesia of extremities, anorexia or uncontrollable hunger, diarrhea, muscle contracture, delirium, sometimes a tabes-like complex. Gangrenous type: pustules may form, limbs swell and become hot, and gangrene may follow. [44] Cattle: gastrointestinal irritation, gangrene of extremities, uterine contractions, nervous disturbances [45].	Occurs on rye, wheat, oats, barley, and other grasses; cause of many cases of poisoning (ergotism) in man and livestock [4,45]. Ergot preparations valued medicinally, chiefly for effect on muscles of uterus [17]; ergometrine causes abortion [18].
11	*Colchicum autumnale* (autumn crocus); entire plant, principally mature corms [38], seeds [32]; United States, Europe, N. Africa [17]	Colchicine [34]	Man: burning in throat; 6-8 hours later a feeling of suffocation, oppression in chest, difficulty in swallowing, vomiting, diarrhea, colic, tenesmus, giddiness, weakness in legs, arthralgia, cyanosis, labored breathing, convulsions [31,45]. Death from respiratory exhaustion in 7-36 hours; consciousness preserved to end. Other animals: nausea, vomiting, colic, diarrhea, hematuria, depression, unconsciousness, paralysis, mydriasis, profuse perspiration, death in 1-3 days [45].	Widely grown in flower gardens. Colchicine arrests mitosis [32]; employed in treatment of gout [43]; also used in plant breeding.
12	*Conium maculatum* (poison hemlock); fruit, especially unripe; stems, leaves, roots; N. America, temperate S. America, Europe, N. Africa, Asia [17,34]	Coniine, conhydrine, *N*-methylconiine, coniceine [9,34]; 3 other alkaloids reported [51]	Man: mydriasis [17]; paralysis of extremities, muscular weakness, often blindness, death from respiratory paralysis [23,34]. Cattle: mydriasis [17]; inappetence, salivation, bloating, muscular weakness [34]; coma [23]. Horses: mydriasis [17]; nausea, grinding of teeth, rapid and labored respiration, paralysis, death from respiratory failure [23].	Leaves most toxic when plant is flowering; root less toxic in spring [34]. Resemblance of fruit to anise, leaves to parsley, and root to parsnips responsible for many human fatalities [17]. Plant commonly fatal to livestock [8].

continued

	Plant (Common Name); Toxic Portion; Distribution	Toxic Principle	Signs and Symptoms Produced	Remarks
	(A)	(B)	(C)	(D)
13	*Croton tiglium* (purging croton); roots, leaves, bark, seeds; southern Asia, E. Indies, Pacific Islands, Africa [40]	Crotin, croton resin [37]; ricinine [51]	Vomiting, drastic purging, possibly collapse and death [40]. Croton oil is a skin irritant, causing reddening, swelling, pustules [7].	Croton oil formerly a human and veterinary purgative; abandoned as too violent. Now used to lubricate machinery. Smoke from burning wood inflames eyes [7].
14	*Datura stramonium* (jimsonweed datura), *D. metel* (Hindu datura), and other species; entire plant, especially seeds; temperate, tropical and subtropical regions	Hyoscine, also hyoscyamine (optically active forms), and the racemic mixture, atropine [3]	Man: headache, nausea, vertigo, thirst, dry and burning sensation in skin, loss of muscular control, mydriasis. Acute poisoning results in mania, convulsions, death [34]; nonfatal poisoning usually causes loss of memory, mental confusion [40,45]. Cattle: mydriasis, suspension of secretions or diarrhea, rapid heart action, paralysis, death from asphyxia. Swine: convulsive twitching [23].	Daturas widely grown for ornament. Children poisoned by eating seeds or sucking flower. In Asia and Africa, adults poisoned by ingesting seeds for intoxicating effect. Accidental mixing of seed with grain, or gathering of young plants with other greens, also responsible for poisoning. [50] Products used medicinally, also criminally, for narcotic effect [45].
15	*Delphinium* spp. (larkspur); seeds, leaves; to a lesser degree, roots; north temperate regions, especially western United States	Delphinine, delphinoidine, delphisine, staphisagroine [34]; 30 other alkaloids reported [51]	Man: burning and inflammation of mouth and pharynx, lowered blood pressure, nausea, abdominal pain, labored respiration, itching, cyanosis. Other animals: uneasiness, stiffness, staggering, constipation, frothing at mouth, nausea, bloating [34]; spasms, respiratory failure [49].	Second to *Astragalus* in causing fatalities among livestock in U.S. [34]; leaves and seeds may cause dermatitis. Horticultural varieties common in flower gardens. Seeds long used in insecticide [49].
16	*Digitalis purpurea* (common foxglove), and *D. lanata* (Grecian foxglove); entire plant, especially seeds, leaves; western Europe, western United States, other areas [23]	*D. purpurea*: diacetyldigilanid A and B; *D. lanata*: digilanid A, B, and C	Anorexia, nausea, vomiting, slow and pronounced pulse in early stages [34]; cardiac arrhythmias, diarrhea, abdominal pain, headache, fatigue, malaise, drowsiness, convulsions, rapid irregular pulse, death in severe cases [19].	Common in flower gardens [34]. Dry plants in hay have poisoned horses and cattle; fresh leaves fatal to turkeys [17]. Digitalis and derivatives used in cardiovascular therapy [37].
17	*Dioscorea hispida* (wild yam); entire plant, tubers; southern Asia, E. Indies, Pacific Islands [7]	Dioscorine [40,50]	Discomfort, then burning, in throat; giddiness, vomiting of blood, suffocation, drowsiness, exhaustion [7]; paralysis of nervous system [40,50].	Raw tubers a frequent cause of death in Philippines [40]. Edible after grating, boiling, repeated washing and soaking [7].
18	*Erythroxylon coca* (Huanuco cocaine tree); leaves; northern S. America, tropics of both hemispheres [40]	Cocaine; 13 other alkaloids reported [51]	Acute: general central nervous system stimulation, followed by depression, numbness of tongue, paralysis of respiratory centers, cyanosis, shallow and irregular breathing, often sudden death from asphyxia [44].	Leaves commonly chewed as a stimulant by Indians of Peru and Bolivia. Cocaine used as a local anesthetic; misused by drug addicts.
19	*Euphorbia* spp. (euphorbia); milky sap; worldwide [34]	A complex substance, euphorbiosteroid [17]; euphorbon, euphorboresene, and an acrid substance reported [7, 9,34,52]; also cyanogenetic glucosides in some species [18]	Man: dermatitis, eye irritation, temporary blindness [23]; swelling around mouth and eyes, burning in mouth and throat, sneezing, vomiting, diarrhea, hemorrhagic gastroenteritis [49]; fainting, death [7,34]. Other animals: blistering of skin, loss of hair, weakness, collapse, death [34].	Various species grown for ornament. Euphorbium derived from *E. resinifera* (gum euphorbia), formerly used medicinally, now in paint as protectant [7]; *Euphorbia* sap mixed with arrow poison as cohesive irritant [49].
20	*Helleborus niger* (black Christmas rose); rootstock, leaves; Europe, United States [34]	Helleborin, helleborein, hellebrin [17, 34,37]	Man: severe dermatitis in some individuals [34]; violent inflammation of mucous membranes of stomach and intestines [36]; vomiting, dizziness, convulsions, sometimes death; effect on heart similar to digitalis [37].	Cultivated in flower gardens; rootstock formerly source of an official drug [37].

continued

97. PLANT TOXINS

	Plant (Common Name); Toxic Portion; Distribution	Toxic Principle	Signs and Symptoms Produced	Remarks
	(A)	(B)	(C)	(D)
21	***Hippomane mancinella*** (manchineel); milky sap, fruit; Florida, Central America, northern S. America, W. Indies [27]	Physostigmine or similar alkaloid, plus a sapogenin [27]	Man: severe burning of skin, swelling and possibly hemorrhage in eyes; temporary blindness from sap. [1,27] Fruit causes gastroenteritis which may be fatal; ulceration of intestinal tract proceeds slowly [27,34].	Apparently more toxic in summer than in winter [27]. Sap used as arrow poison; smoke from burning wood toxic [1].
22	***Hyoscyamus niger*** (black henbane); entire plant, especially leaves; northwestern United States, Canada [34], Mediterranean region, Asia, Oceania	Hyoscyamine, hyoscine, atropine, and other alkaloids [22, 34,36]	*See Atropa belladonna*	Usually avoided by animals because of unpleasant taste. Children poisoned by eating seeds and pods [34]. Roots mistaken for parsnips [17]. Leaves and flowering tops used in medicine [35].
23	***Jatropha curcas*** (Barbados nut); seeds, milky sap; tropics [49], southern Florida	Curcin [50]	Man: burning in throat, bloating, dizziness, vomiting, diarrhea, drowsiness, possibly dysuria and mydriasis [45]; severe leg cramps, deafness [24]; violent purgative action often fatal to children [1]. Other animals: hemorrhagic enteritis, staggering, dull vision, mydriasis, bloating, paralysis, somnolence, convulsions, fever, shivering, coma, death in 1-3 days in acute cases [45].	Sap used as fish poison [7]; seeds yield "hell oil," formerly given as purgative, now used for soap in Cape Verde Islands and Ecuador. Seeds of *J. multifida*, a tropical ornamental, often cause poisoning in children.
24	***Kalmia latifolia*** (mountain laurel), and *K. angustifolia* (lambkill kalmia); all parts except wood; northeastern United States, Canada, Pacific coast [8]	Andromedotoxin [34]	Man: similar to symptoms produced in other animals, plus pain in head, sweating, tingling of skin [10]. Other animals (usually sheep): salivation, flow of tears, secretions from nose, frothing at mouth, impaired vision or blindness, dizziness, irregular respiration, vomiting, convulsions, paralysis of limbs, coma, death [8,34].	Children have been poisoned by eating leaves mistaken for wintergreen [8]. Frequent cause of fatal poisoning of livestock, especially sheep.
25	***Lathyrus sativus*** (grass peavine); seeds, mature plant; southern United States, southern Europe, N. Africa, Asia [34,45]	β-Aminopropionitrile [47]	Man: pain in back [49]; sudden weakness in legs; further ingestion may cause leg paralysis. Other animals: similar to symptoms produced in man, plus asphyxia. Cattle also develop constipation, weak pulse, numbness of skin [45]; general weakening of tendons and ligaments, tissue fragility; connective tissue malformations, such as exostoses, hernias, and aneurysms [47].	*L. sativus*, *L. cicera*, and *L. clymenum* used as food and fodder [49], but cause many cases of lathyrism in man and livestock [45]. *L. odoratus*, the sweet pea of flower gardens, has fatally poisoned children.
26	***Leucaena glauca*** (white popinac lead tree); leaves (especially immature), bark, roots; southern United States, tropics [40,46]	Mimosine (leucenol) [46]	Horses, mules, donkeys: alopecia of manes and tails, possibly deformation or loss of hoofs [23,50]; in severe cases, lameness, debility, death from hunger and thirst [18]. Swine: total alopecia, impaired vision, emaciation, various degrees of paralysis, respiratory failure [23,50].	A fodder plant for cattle, sheep, goats (immune to toxicity) [23]. Ripe seeds used as coffee substitute [39]. Young leaves and unripe seeds, cooked as vegetables, occasionally cause loss of hair in humans [30].
27	***Lupinus*** spp. (lupine); seeds most toxic, pods less, leaves least; temperate regions [45]	Lupanine and 30 other alkaloids reported [51]	Liver damage due to poisoning by ingestion. European lupinosis, chronic: anemia, cachexia. Acute: fever, general jaundice, coma, paralysis, constipation, then hemorrhagic diarrhea, swelling of ears, eyelids, lips, nose. American lupinosis: frothing at mouth, dyspnea, frenzied actions, nausea, bloating, coma, possibly death [17,18, 45].	Toxicity varies with season and location; some species harmless [34]. Many livestock deaths, especially of sheep, from ingestion of lupine seeds in quantity [18].

continued

97. PLANT TOXINS

	Plant (Common Name); Toxic Portion; Distribution	Toxic Principle	Signs and Symptoms Produced	Remarks
	(A)	(B)	(C)	(D)
28	*Manihot esculenta* (cassava); roots (especially skin and juice), mature leaves, stems, fruit; tropics [7,40]	Cyanogenetic glucosides [42]	Man, livestock: nausea [50]; rapid and labored breathing; rapid, irregular, weak pulse; twitching, staggering, spasms of neck and legs, convulsions, mydriasis, coma, death from respiratory paralysis [45].	Bitter cultivars, high in CN^-, yield starch for tapioca; sweet cultivars, with little or no CN^-, widely cooked as starchy vegetables [42].
29	*Melia azedarach* (chinaberry); fruit pulp, bark, flowers; southern United States, tropical America, S. Africa, southwestern Asia [45]	Azadarin (margosine) affects central nervous system [34, 45,49]	Man, leaf poisoning: stomatitis, decrease in urine formation, violent and bloody vomiting [45]. Fruit poisoning: nausea, vomiting, labored breathing, palpitation, paralysis [34]. Other animals (especially swine): vomiting, colic, diarrhea, labored breathing, cyanosis, convulsions or paralysis, death by asphyxia [49].	Common shade tree. Roots, bark, leaves, flowers, fruit used for stupefying fish [1]; various parts of tree used in folk medicine [49]; seeds yield medicinal oil [49].
30	*Metopium toxiferum* (poisonwood); entire plant, especially sap; southern Florida, W. Indies [11], Bahamas	Probably similar to poison ivy	Dermatitis similar to that caused by poison ivy [11,34]. Blistering may continue for weeks, readily spreading from one area to another; may be accompanied by intense itching, burning. Severe cases require hospitalization.	Smoke from burning wood highly irritating [12]. Clear, sticky sap turns black on exposure to air.
31	*Nerium oleander* (oleander); leaves, bark, roots, flowers; southern United States, tropics, subtropics [40]	Principally neriin, oleandrin, and folinerin, resembling digitalis in action; rosagenin (in bark) similar to strychnine [49]	Man: vomiting, slow and irregular pulse, bloody diarrhea, death from cardiac or respiratory paralysis. Other animals: similar to symptoms produced in man, plus sweating, gnashing of teeth, groaning, sometimes polyuria [45].	Popular ornamental shrub. Often poisons grazing animals; 15-20 g fresh plant fatal to horse. Smoke from burning plant toxic; meat roasted on skewers of oleander wood, or food stirred with oleander sticks, fatally toxic [1,23,45].
32	*Papaver somnif*[illegible] (opium poppy); milky exudate [illegible] incised unripe seed pod, which is dried as "opium" [34]; southern Europe, Asia, tropics, subtropics	[illegible]rphine (chiefly); [illegible]so codeine, the[illegible]aine, papaverine, and narcotine [45]	Acute: central nervous system depression, symmetrical pinpoint pupils, depressed respiration, cyanosis, coma, death from depression of respiration and circulation. Chronic: varies with individual case [48].	Cultivated in flower gardens as well as for commercial drug production. Animals infrequently poisoned by eating seed pods [34]. Seeds harmless, commonly used in bakery products.
33	*Phytolacca americana* (pokeberry); roots, seeds, mature (red) stems; eastern & southern United States [34], Europe, S. Africa [49]	Phytolaccine [51]	Burning and bitterness in mouth, vomiting, purging, spasms, sometimes convulsions, death from respiratory paralysis [34].	Young shoots edible if well-cooked [34]; fruit juice harmless, used as food coloring [49]. Root has been accidentally gathered with shoots, or mistaken for parsnips or horseradish [34,49].
34	*Prunus* spp. (chokecherry, other wild cherries); leaves (especially wilted), bark, seeds; northern hemisphere, Orient [34]	Hydrocyanic acid formed by action of enzymes upon amygdalin (?) or prunasin [34]	Animals: uneasiness, staggering, falling, convulsions, labored breathing, bloating, death [34].	Frequent cause of fatal poisoning of livestock [34].
35	*Rhus toxicodendron* (poison ivy), and *R. vernix* (poison sumac); entire plant; N. America [34]	Urushiol [14]	Man: skin irritation, swelling, blisters, extreme discomfort, itching; sometimes fatal to children [34].	Smoke from burning plant toxic; estimated 1,000,000 Americans get ivy poisoning each year [14].
36	*Ricinus communis* (castor bean); seeds; southern United States, tropics, subtropics [34]	Ricin (a toxalbumin), and the less toxic alkaloid, ricinine [18]; also a castor bean allergen [41]	Man: burning in mouth, throat, stomach; vomiting; diarrhea; thirst; rapid, then faint pulse; cramps of abdomen, legs; convulsions; shallow respiration. Other animals: hemorrhagic enteritis,	Some varieties cultivated as ornamentals; 2-3 seeds may be fatal to child, 6 may kill horse [49]. Seeds yield castor

continued

	Plant (Common Name); Toxic Portion; Distribution	Toxic Principle	Signs and Symptoms Produced	Remarks
	(A)	(B)	(C)	(D)
	Ricinus communis (*See* preceding page)		staggering, dulled vision, heart weakness, bloating, paralysis, convulsions, fever, shivering, coma, death in 1-3 days [45].	oil; processors subject to conjunctivitis, dermatitis, and respiratory allergy; efforts being made to detoxify protein-rich presscake for feed [41].
37	*Senecio* spp. (groundsel); entire plant, especially seeds; worldwide	Of numerous toxic alkaloids isolated, senecifolidine, isatidine, pterophine, retrorsine, scleratine, and senecionine are responsible for "bread poisoning" and liver cirrhosis [49].	Man: abdominal pain, vomiting, ascites, enlarged liver, emaciation, bloody diarrhea. Generally fatal if not treated early; when not immediately fatal, liver damage may bring about subsequent death [45]. Grazing animals: yawning, inappetence, emaciation, staggering, colic [34]; unconsciousness, death from liver cirrhosis [49].	Seeds of various species in harvested grain considered responsible for "bread poisoning" [13]; senecio poisoning common in livestock [34].
38	*Strophanthus* spp. (strophanthus); seeds, roots, bark; southern Florida, tropical America, tropical Africa [40]	An alkaloid, trigonelline [51], and 64 cardiac glucosides and aglycons reported [49]	Vomiting, slow and irregular pulse, blurred vision, delirium, death from circulatory failure of cardiac origin [13,44].	Arrow poisons from several species [40]. *S. sarmentosus* is source of sarmentogenin, which is chemically converted to cortisone [33,49].
39	*Strychnos nuxvomica* (nuxvomica poison nut); seeds, leaves, bark, wood, flowers; India, Hawaii [2,23,40]	Strychnine, brucine [40]; six other alkaloids reported [51]	Action on spinal cord causes excessive reflex irritability, followed by rapid tonic convulsions with intermissions of exhaustion and sweating; extreme muscular rigidity, asphyxia, death. Mind not affected [40].	Strychnine formerly used as stimulant; tonic in minute amounts [40]. Children poisoned by pills. Poisoned grain used as gopher bait.
40	*S. toxifera* (curare poison nut); bark, roots; Central America, northern S. America [1]	Principally toxiferines I-XII [29], caracurines I-IX; 12 other alkaloids reported [51]	Haziness of vision, relaxation of facial muscles, inability to raise head, loss of muscular contraction in arms and legs, depressant effects on muscles of respiration, muscle nerve end-plate paralysis [15].	Often main ingredient in certain kinds of curare famed as Indian blowgun poison [15,29]. Tubocurarine chloride (U.S.P.) now used as skeletal muscle relaxant in shock therapy and as diagnostic aid [25].
41	*Thevetia peruviana* (thevetia); seeds, leaves, bark, roots, milky sap; tropics [7,40]	Thevetin, thevetoxin, neriifolin [49]	Man: vomiting, diarrhea, high blood pressure, erratic heart beat, death from asphyxiation and sudden heart paralysis [2,40]. Contact with sap may inflame and blister skin [1].	Seeds used as fish poison, and for suicide and homicide.
42	*Veratrum viride* (American false hellebore); entire plant; United States, Canada [8, 26]	Protoveratrine A and B, germerine, jervine; 15 other alkaloids reported [51]	Man: vomiting, abdominal pain, muscular weakness, spasms, possibly convulsions, rapid pulse, shallow breathing, semiconsciousness, death from asphyxia [34].	This and related species yield veratrum, a therapeutic agent for hypertension [26].
43	*Zigadenus* spp. (death camas); leaves, stems, flowers, bulb; northern hemisphere, especially United States [34,38]	Zygadenine, similar to veratrine and cevadine in action [34]	Animals: salivation, vomiting, lowered temperature, staggering or collapse, labored breathing, paralysis, possibly coma and death [5,34].	Frequent cause of fatal poisoning of livestock. Children occasionally poisoned by eating bulb [34].

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X. BIOPHYSICAL AND BIOCHEMICAL CHARACTERISTICS

98. CARBOHYDRATES: PHYSICAL AND CHEMICAL CHARACTERISTICS

All data are for crystalline substances, unless otherwise specified. In Parts I-V, the selection of substances was restricted to natural carbohydrates found free (or in chemical combination and released on hydrolysis) and to biological oxidation products of the natural carbohydrates. In Part VI, the selection of oligosaccharides was restricted to those substances found free. The nomenclature conforms with that of the British-American report as published in the *Journal of Organic Chemistry*, 28:281 (1963). Substances have been arranged alphabetically under the name of the parent sugar within groups formulated according to increasing carbon content (excluding carbon in substituents), with synonymous common names in parentheses. **Melting Point:** b.p. = boiling point; d. = decomposes; s. = sinters. **Specific Rotation** was determined in water at concentrations of 1-5 g per 100 ml of solution and at 20°-25°C, unless otherwise specified; other temperatures or wavelengths are shown in brackets; *c* = grams solute per 100 ml of solution. The literature has been covered by means of *Chemical Abstracts* through 1962.

Part I. NATURAL MONOSACCHARIDES: ALDOSES AND KETOSES

	Substance (Synonym)	Chemical Formula	Melting Point °C	Specific Rotation $[\alpha]_D$	Reference
	(A)	(B)	(C)	(D)	(E)
	Aldoses				
1	D-Glyceraldehyde	$C_3H_6O_3$	....	+13.5±0.5 (syrup)	122
2	D-Glyceraldehyde, 3-deoxy-3,3-*C*-bis(hydroxymethyl)- (Cordycepose)	$C_5H_{10}O_4$	....	-26 (*c* 0.6, C_2H_5OH)	9,10
3	D-Glyceraldehyde, 3,3-bis(*C*-hydroxymethyl)- (Apiose)	$C_5H_{10}O_5$	....	+5.6 (*c* 10) [15°] (syrup)	101,114
4	β-D-Arabinose	$C_5H_{10}O_5$	155	-175 → -103	38,46,97,99
5	D-Arabinose, 2-*O*-methyl-	$C_6H_{12}O_5$	Syrup	-102	38,73
6	α-L-Arabinose	$C_5H_{10}O_5$	158 amorphous	+55.4 → +105	112
7	β-L-Arabinose	$C_5H_{10}O_5$	160	+190.6 → +104.5	81
8	DL-Arabinose	$C_5H_{10}O_5$	163.5-164.5	None	98,121
9	α-L-Lyxose	$C_5H_{10}O_5$	105	+5.8 → +13.5	1
10	L-Lyxose, 5-deoxy-3-*C*-formyl- (Streptose)	$C_6H_{10}O_5$	....	....	61
11	L-Lyxose, 3-*C*-formyl- (Hydroxystreptose)	$C_6H_{10}O_6$	....	....	108
12	Pentose, 4,5-anhydro-5-deoxy-D-*erythro*-	$C_5H_8O_3$	....	....	47
13	Pentose, 2-deoxy-D-*erythro*-	$C_5H_{10}O_4$	96-98	-91 → -58	24
14	D-Ribose	$C_5H_{10}O_5$	87	-23.1 → -23.7	87
15	D-Ribose, 2-*C*-hydroxymethyl- (Hamamelose)	$C_6H_{12}O_6$	....	-7.1 [λ 578]	33
16	α-D-Xylose	$C_5H_{10}O_5$	145	+93.6 → +18.8	50,52
17	D-Xylose, 5-deoxy-	$C_5H_{10}O_4$	....	+16	36
18	β-D-Xylose, 2-*O*-methyl-	$C_6H_{12}O_5$	137-138	-21 → +34	64,65,73
19	α-D-Xylose, 3-*O*-methyl-	$C_6H_{12}O_5$	95	+45 → +19	5,64,65
20	D-Allose, 6-deoxy-	$C_6H_{12}O_5$	140-143 146-148	+1.6 [18°] (*c* 0.6) -4.7 → 0	57 25
21	D-Allose, 6-deoxy-2,3-di-*O*-methyl- (Mycinose)	$C_8H_{16}O_5$	102-106	-46 → -29	25
22	Amicetose (a trideoxy hexose)	$C_6H_{12}O_3$	Oil, b.p. 65-70	+28.6 ($CHCl_3$)	106
23	Antiarose	$C_6H_{12}O_5$	....	Levo	60
24	α-D-Galactose	$C_6H_{12}O_6$	167	+150.7 → +80.2	96
25	β-D-Galactose	$C_6H_{12}O_6$	143-145	+52.8 → +80.2	96,124
26	D-Galactose, 3,6-anhydro-	$C_6H_{10}O_5$	....	+21.3 [10°]	4,85
27	α-D-Galactose, 6-deoxy- (D-Fucose; Rhodeose)	$C_6H_{12}O_5$	140-145	+127 → +76.3 (*c* 10)	116
28	D-Galactose, 6-deoxy-3-*O*-methyl- (Digitalose)	$C_7H_{14}O_5$	106[1], 119[2]	+106	66
29	D-Galactose, 6-deoxy-4-*O*-methyl-	$C_7H_{14}O_5$	131-132	+82	34
30	D-Galactose, 6-deoxy-2,3-di-*O*-methyl-	$C_8H_{16}O_5$	....	+73	58,102
31	α-D-Galactose, 3-*O*-methyl-	$C_7H_{14}O_6$	144-147	+150.6 → +108.6	89
32	α-D-Galactose, 6-*O*-methyl-	$C_7H_{14}O_6$	122-123	+117 → +77.3	40,83
33	L-Galactose	$C_6H_{12}O_6$	....	*See* D-Galactose	
34	α-L-Galactose, 3,6-anhydro-	$C_6H_{10}O_5$	....	-39.4 → -25.2	3
35	α-L-Galactose, 6-deoxy- (L-Fucose)	$C_6H_{12}O_5$	145	-124.1 → -76.4	77
36	L-Galactose, 6-deoxy-2-*O*-methyl-	$C_7H_{14}O_5$	149-150	-75±4 (*c* 0.5)	2
37	L-Galactose, 6-sulfate	$C_6H_{12}O_9S$	....	-47 (*c* 0.2) (Na salt)	111
38	DL-Galactose	$C_6H_{12}O_6$	143-144, 163	None (racemic)	82,115
39	α-D-Glucose	$C_6H_{12}O_6$	146, 83 (H_2O)	+112 → +52.7	7
40	β-D-Glucose	$C_6H_{12}O_6$	148-150	+18.7 → +52.7	7
41	D-Glucose, 6-acetate	$C_7H_{14}O_7$	135	+48	26
42	D-Glucose, 2,3-di-*O*-methyl-	$C_8H_{16}O_6$	85-86, 121	+50	22,58,119

/1/ Original melting point. /2/ Melting point after four-months' storage.

continued

98. CARBOHYDRATES: PHYSICAL AND CHEMICAL CHARACTERISTICS

Part I. NATURAL MONOSACCHARIDES: ALDOSES AND KETOSES

	Substance (Synonym)	Chemical Formula	Melting Point °C	Specific Rotation $[\alpha]_D$	Reference
	(A)	(B)	(C)	(D)	(E)
	Aldoses				
43	D-Glucose, 6-*O*-benzoyl- (Vaccinin)	$C_{13}H_{16}O_7$	Amorphous	+48 (C_2H_5OH)	84
44	α-D-Glucose, 6-deoxy- (Chinovose; Epirhamnose; Glucomethylose; Isorhamnose; Isorhodeose; Quinovose)	$C_6H_{12}O_5$	139-140	+73.3 → +29.7 (*c* 8)	88
45	α-D-Glucose, 6-deoxy-3-*O*-methyl- (D-Thevetose)	$C_7H_{14}O_5$	116	+84 → +33	32
46	D-Glucose, 6-sulfonic acid, 6-deoxy- (6-Sulfoquinovose)	$C_6H_{12}O_8S$	173-174	+87[3]	80
47	D-Glucose, 3-*O*-methyl-	$C_7H_{14}O_6$	162-167	+98 → +59.5	19
48	α-L-Glucose	$C_6H_{12}O_6$	141-143	-95.5 → -51.4	27
49	L-Glucose, 6-deoxy-3-*O*-methyl- (L-Thevetose)	$C_7H_{14}O_5$	126-129	-36.9±2	15
50	D-Gulose, 6-deoxy-	$C_6H_{12}O_5$	...	...	30,31,70
51	Hexose, 2-deoxy-D-*arabino*-[4]	$C_6H_{12}O_5$	148	+46.6 [18°]	9,10
52	Hexose, 2,6-dideoxy-3-*O*-methyl-D-*arabino*- (D-Oleandrose)	$C_7H_{14}O_4$	...	-11	110
53	Hexose, 3,6-dideoxy-D-*arabino*- (Tyvelose)	$C_6H_{12}O_4$	...	+24±2	30
54	Hexose, 2,6-dideoxy-3-*O*-methyl-L-*arabino*- (L-Oleandrose)	$C_7H_{14}O_4$	62-63	+11.9±2.5	16
55	Hexose, 3,6-dideoxy-L-*arabino*- (Ascarylose)	$C_6H_{12}O_4$	...	-24±2	30
56	Hexose, 2,6-dideoxy-3-*O*-methyl-D-*lyxo*- (Diginose)	$C_7H_{14}O_4$	90-92	+56±4	105,109
57	Hexose, 2,6-dideoxy-L-*lyxo*- (L-Fucose, 2-deoxy-)	$C_6H_{12}O_4$	103-106	-61.6	53,125
58	Hexose, 2,6-dideoxy-3-*O*-methyl-L-*lyxo*-	$C_7H_{14}O_4$	78-85	-65	93
59	Hexose, 2,6-dideoxy-D-*ribo*- (Digitoxose; D-Altrose, 2,6-dideoxy-)	$C_6H_{12}O_4$	110	+46.4	59,76
60	Hexose, 2,6-dideoxy-3-*O*-methyl-D-*ribo*- (Cymarose)	$C_7H_{14}O_4$	93	+52	54
61	Hexose, 3,6-dideoxy-D-*ribo*- (Paratose)	$C_6H_{12}O_4$	...	+10±2(*c* 0.9)	23,31
62	Hexose, 4,6-dideoxy-3-*O*-methyl-D-*ribo*- (D-Gulose, 4,6-dideoxy-3-*O*-methyl-; Chalcose)	$C_7H_{14}O_4$	96-99	+120 → +76	25
63	Hexose, 2,6-dideoxy-D-*xylo*- (Boivinose)	$C_6H_{12}O_4$	96-98	-3.9 → +3.9	17
64	Hexose, 2,6-dideoxy-3-*O*-methyl-D-*xylo*- (Sarmentose)	$C_7H_{14}O_4$	78-79	+12 → +15.8	55
65	Hexose, 3,6-dideoxy-D-*xylo*- (Abequose)	$C_6H_{12}O_4$	...	-3.2±0.6	118
66	Hexose, 2,6-dideoxy-3-*C*-methyl-L-*xylo*- (Mycarose)	$C_7H_{14}O_4$	128-129	-31.1	90
67	Hexose, 2,6-dideoxy-3-*C*-methyl-3-*O*-methyl-L-*xylo*- (Cladinose)	$C_8H_{16}O_4$	oil, b.p. 120-132 (0.25 mm)	-23.1	29
68	Hexose, 3,6-dideoxy-L-*xylo*- (Colitose)	$C_6H_{12}O_4$	...	+4 (H_2O); -51±2 (CH_3OH)	72
69	D-Idose[5]	$C_6H_{12}O_6$	...	...	41
70	L-Idose, 1,6-anhydro-	$C_6H_{10}O_5$	...	...	6
71	α-D-Mannose	$C_6H_{12}O_6$	133	+29.3 → +14.5	68,69
72	β-D-Mannose	$C_6H_{12}O_6$	132	-16.3 → +14.5	95
73	D-Mannose, 6-deoxy- (D-Rhamnose)	$C_6H_{12}O_5$	86-90	-7.0	75
74	α-L-Mannose, 6-deoxy-monohydrate (L-Rhamnose)	$C_6H_{14}O_6$	93-94	-8.6 → +8.2	8,52
75	β-L-Mannose, 6-deoxy-	$C_6H_{12}O_5$	123-125	+38.4 → +8.9	28
76	L-Mannose, 6-deoxy-2-*O*-methyl-	$C_7H_{14}O_5$	...	...	74
77	L-Mannose, 6-deoxy-3-*O*-methyl- (L-Acofriose)	$C_7H_{14}O_5$	114-115	+30 [18°]	45
78	L-Mannose, 6-deoxy-2,4-di-*O*-methyl-	$C_8H_{16}O_5$	82	-19 [16°]	20,74
79	L-Mannose, 6-deoxy-5-*C*-methyl-4-*O*-methyl- (Noviose)	$C_8H_{16}O_5$	128-130	+19.9 (50% C_2H_5OH)	44
80	Rhodinose (a 2,3,6-trideoxyhexose)	$C_6H_{12}O_3$	...	-11±1.6	18
81	D-Talose	$C_6H_{12}O_6$	128-132	+16.9	120
82	D-Talose, 6-deoxy- (D-Talomethylose)	$C_6H_{12}O_5$	129-131	+20.6	75
83	L-Talose, 6-deoxy- (L-Talomethylose)	$C_6H_{12}O_5$	116-118	-19.5±2 [18°]	103
84	L-Talose, 6-deoxy-2-*O*-methyl- (L-Acovenose)	$C_7H_{14}O_5$	...	-19.4	113
85	Heptose, D-*glycero*-D-*galacto*-	$C_7H_{14}O_7$	139-140	+47 → +64 (*c* 0.5)	104
86	Heptose, D-*glycero*-D-*manno*-	$C_7H_{14}O_7$	...	...	86,94
87	Heptose, D-*glycero*-L-*manno*-	$C_7H_{14}O_7$	...	...	78,79
	Ketoses				
88	Dihydroxyacetone	$C_3H_6O_3$	80 (dimer)	None	42

/3/ As a methyl glycoside cyclo-hexylamine salt. /4/ Included because of speculations concerning it in biological processes. /5/ Either D-idose or L-altrose is in the polysaccharide varianose.

continued

98. CARBOHYDRATES: PHYSICAL AND CHEMICAL CHARACTERISTICS

Part I. NATURAL MONOSACCHARIDES: ALDOSES AND KETOSES

	Substance (Synonym)	Chemical Formula	Melting Point °C	Specific Rotation $[\alpha]_D$	Reference
	(A)	(B)	(C)	(D)	(E)
	Ketoses				
89	Tetrulose, L-*glycero*-[6] (L-Erythrulose; Ketoerythritol; L-Threulose)	$C_4H_8O_4$	Syrup	+12	11,12
90	Pentulose, D-*erythro*- (Adonose; D-Ribulose)	$C_5H_{10}O_5$	Syrup	+16.6 [27°]	71
91	Pentulose, L-*erythro*- (L-Ribulose)	$C_5H_{10}O_5$	....	-16.6	92
92	Pentulose, D-*threo*- (D-Xylulose)	$C_5H_{10}O_5$	....	-33	43
93	Pentulose, 5-deoxy-D-*threo*-	$C_5H_{10}O_4$	....	-5±1 (CH_3OH)	36
94	Pentulose, L-*threo*- (L-Xylulose; L-Lyxulose; Xyloketose)	$C_5H_{10}O_5$	Syrup	+33.1	67
95	Hexulose, β-D-*arabino*- (β-D-Fructose; Levulose)	$C_6H_{12}O_6$	102-104[7]	-133.5 → -92	49,51,126, 127
96	Hexulose, 6-deoxy-D-*arabino*- (D-Rhamnulose)	$C_6H_{12}O_5$	....	-13±2	48
97	Hexulose, D-*lyxo*- (D-Tagatose)	$C_6H_{12}O_6$	131-132	+2.7 → -4, -5	91
98	5-Hexulose, D-*lyxo*-	$C_6H_{12}O_6$	158	-86.6	117
99	Hexulose, 6-deoxy-L-*lyxo*- (L-Fuculose)	$C_6H_{12}O_5$	....	....	37
100	Hexulose, D-*ribo*- (D-Psicose)	$C_6H_{12}O_6$	Amorphous	+4.7	14,123
101	Hexulose, L-*xylo*- (L-Sorbose)	$C_6H_{12}O_6$	159-161	-43.1	100
102	Hexulose, 6-deoxy-L-*xylo*-	$C_6H_{12}O_5$	88	-25±2 (*c* 0.7)	48
103	Heptulose, D-*altro*- (Sedoheptulose; Sedoheptose)	$C_7H_{14}O_7$	Amorphous	+2.5 (*c* 10)	63
104	Heptulose·hemihydrate, L-*galacto*- (Perseulose)	$C_7H_{14}O_7 \cdot 1/2\ H_2O$	110-115	-90 → -80	13,39
105	Heptulose, L-*gulo*-	$C_7H_{14}O_7$	....	-28	107
106	Heptulose, D-*ido*-	$C_7H_{14}O_7$	172	-34±8 (*c* 0.3)	35
107	Heptulose, D-*manno*- (Mannoketoheptose; D-Mannotagatoheptose)	$C_7H_{14}O_7$	152	+29.4	62
108	Heptulose, D-*talo*-	$C_7H_{14}O_7$	....	....	21
109	Octulose, D-*glycero*-L-*galacto*-	$C_8H_{16}O_8$	....	-57, -43.4 → -13.4	56,104
110	Octulose, D-*glycero*-D-*manno*-	$C_8H_{16}O_8$	....	+20 (CH_3OH)	21

/6/ Early literature refers to this as D-erythrose. /7/ The $\cdot 1/2\ H_2O$ and $\cdot 2H_2O$ forms also exist.

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Part I. NATURAL MONOSACCHARIDES: ALDOSES AND KETOSES

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Part II. NATURAL MONOSACCHARIDES: AMINO SUGARS

	Substance (Synonym)	Chemical Formula	Melting Point °C	Specific Rotation $[\alpha]_D$	Reference
	(A)	(B)	(C)	(D)	(E)
	Aldosamines				
1	D-Ribose, 3-amino-3-deoxy-	$C_5H_{11}NO_4$	158-158.5 d.	-24.6 (hydrochloride)	24
2	D-Galactose, 2-amino-2-deoxy- (Galactosamine; Chondrosamine)	$C_6H_{13}NO_5$	185	+121 → +80 (hydrochloride)	14
3	α-L-Galactose, 2-amino-2,6-dideoxy- (L-Fucosamine)	$C_6H_{13}NO_4$	192-193 d.	-119 → -92 [27°] (hydrochloride)	1,13
4	α-D-Glucose, 2-amino-2-deoxy- (Glucosamine; Chitosamine)	$C_6H_{13}NO_5$	88	+100 → +47.5	26
5	β-D-Glucose, 2-amino-2-deoxy-	$C_6H_{13}NO_5$	110-111	+28 → +47.5	26
6	D-Glucose, 3-amino-3-deoxy- (Kanosamine)	$C_6H_{13}NO_5$	128 d.	+19 [14°]	4,16,17
7	D-Glucose, 6-amino-6-deoxy-	$C_6H_{13}NO_5$	161-162 d.	+23 → +50.1 (hydrochloride)	4,16,17
8	D-Glucose, 2,6-diamino-2,6-dideoxy- (Neosamine C)	$C_6H_{14}N_2O_4$	>230	+61.5 (dihydrochlorride)	18,19
9	D-Glucose, 3,6-dideoxy-3-dimethylamino- (Mycaminose)	$C_8H_{17}NO_4$	115-116	+31 (hydrochloride)	7
10	D-Glucose, 4,6-dideoxy-4-dimethylamino-	$C_8H_{17}NO_4$	192-193	+45.5 (hydrochloride)	22
11	L-Glucose, 2-deoxy-2-methylamino-	$C_7H_{15}NO_5$	130-132	-64	27
12	D-Gulose, 2-amino-1,6-anhydro-2-deoxy-	$C_6H_{11}NO_4$	250-260 d.	+41±2 (hydrochloride)	8
13	D-Gulose, 2-amino-2-deoxy-	$C_6H_{13}NO_5$	152-162 d.	+5.6 → -18.7 (hydrochloride)	23
14	Hexose, 3,4,6-trideoxy-3-dimethylamino-D-*xylo*- (Desosamine; Picrocine)	$C_8H_{17}NO_3$	189-191 d.	+49.5 (*c* 10) (hydrochloride)	2
15	Hexose, a 4-acetamido-2-amino-2,4,6-trideoxy-	$C_8H_{16}N_2O_4$	216-219	+115 → +94 [26°] (*c* 0.05)	21
16	Hexose, an amino-deoxy-3-*O*-carboxyethyl-	$C_9H_{17}NO_7$	....	....	20
17	Hexose, a 2,6-diamino-2,6-dideoxy- (Neosamine B; Paramose)	$C_6H_{14}N_2O_4$	135-150 d.	+17.5 (*c* 0.9) (hydrochloride)	18,19
18	Hexose, a 3-dimethylamino-2,3,6-trideoxy- (Rhodosamine)	$C_8H_{17}NO_3$	....	....	3
19	D-Mannose, 2-amino-2-deoxy- (Mannosamine)	$C_6H_{13}NO_5$	142 d.	-4.3 (*c* 9) (hydrochloride)	12
20	D-Mannose, 3-amino-3,6-dideoxy- (Mycosamine)	$C_6H_{13}NO_4$	162	-11.5 (hydrochloride)	25
21	D-Talose, 2-amino-2-deoxy- (Talosamine)	$C_6H_{13}NO_5$	151-153	+3.4 → -5.7 (*c* 0.9) (hydrochloride)	5,11
22	L-Talose, 2-amino-2,6-dideoxy- (Pneumosamine)	$C_6H_{13}NO_4$	162-163	+6.9 → +10.4 (hydrochloride)	1
	Ketosamines				
23	Pentulose, 1-(*o*-carboxyanilino)-1-deoxy-D-*erythro*-	$C_{12}H_{14}NO_6$	....	....	6,15
24	Hexulose, 1-(*o*-carboxyanilino)-1-deoxy-D-*arabino*-	$C_{13}H_{16}NO_7$	....	....	15
25	Hexulose, 5-amino-5-deoxy-L-*xylo*-	$C_6H_{13}NO_5$	174-176	-62	9
26	Hexulose, 6-deoxy-6-(*N*-methylacetamido)-L-*xylo*-	$C_9H_{17}NO_6$	....	....	10

continued

98. CARBOHYDRATES: PHYSICAL AND CHEMICAL CHARACTERISTICS

Part II. NATURAL MONOSACCHARIDES: AMINO SUGARS

Contributors: Wolfrom, Melville L.; Maher, George G.; and Pagnucco, Rinaldo G.

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Part III. NATURAL ALDITOLS AND INOSITOLS (with Inososes and Inosamines)

	Substance (Synonym)	Chemical Formula	Melting Point °C	Specific Rotation $[\alpha]_D$	Reference
	(A)	(B)	(C)	(D)	(E)
	Alditols				
1	Glycerol	$C_3H_8O_3$	20	None	24
2	Glycerol, 1-deoxy- (1,2-Propane-diol)[1]	$C_3H_8O_2$	Oil, b.p. 188-189	None (racemic)	25
3	Erythritol	$C_4H_{10}O_4$	118-120	None (meso)	9
4	Erythritol, 1,4-dideoxy- (2,3-Butyleneglycol)	$C_4H_{10}O_2$	25, 34	None (meso)	57,59
5	D-Threitol, 1,4-dideoxy-	$C_4H_{10}O_2$	19	-13.0	57
6	L-Threitol, 1,4-dideoxy-	$C_4H_{10}O_2$	....	+10.2	21
7	DL-Threitol, 1,4-dideoxy-	$C_4H_{10}O_2$	7.6	None (racemic)	59
8	D-Arabinitol	$C_5H_{12}O_5$	103	+7.82 (*c* 8, borax solution)	6
9	L-Arabinitol	$C_5H_{12}O_5$	101-102	-32 (*c* 0.4, 5% molybdate)	7,47,54
10	Ribitol (Adonitol)	$C_5H_{12}O_5$	102	None (meso)	57
11	Galactitol (Dulcitol)	$C_6H_{14}O_6$	186-188	None (meso)	48
12	D-Glucitol (Sorbitol)	$C_6H_{14}O_6$	112	-1.8 [15°]	56
13	D-Glucitol, 1,5-anhydro- (Polygalitol)	$C_6H_{12}O_5$	140-141	+42.4	46
14	L-Iditol	$C_6H_{14}O_6$	73.5	-3.5 (*c* 10)	10
15	D-Mannitol	$C_6H_{14}O_6$	166	-0.21	13
16	D-Mannitol, 1,5-anhydro- (Styracitol)	$C_6H_{12}O_5$	157	-49.9	60
17	Heptitol, D-*glycero*-D-*galacto*- (Heptitol, L-*glycero*-D-*manno*-; Perseitol)	$C_7H_{16}O_7$	183-185, 188	-1.1	28,36
18	Heptitol, D-*glycero*-D-*gluco*- (Heptitol, L-*glycero*-D-*talo*-; β-Sedoheptitol)	$C_7H_{16}O_7$	131-132	+46 (5% NH_4 molybdate)	14
19	Heptitol, D-*glycero*-D-*manno*- (Heptitol, D-*glycero*-D-*talo*-; Volemitol)	$C_7H_{16}O_7$	153	+2.65	12
20	Octitol, D-*erythro*-D-*galacto*-	$C_8H_{18}O_8 \cdot H_2O$	169-170	-11 (5% NH_4 molybdate)	14
	Inositols				
21	Betitol (a dideoxy inositol)	$C_6H_{12}O_4$	224	....	55
22	Bioinosose (*scyllo*-Inosose; *myo*-Inosose-2; a deoxy keto inositol)	$C_6H_{10}O_6$	198-200	None (meso)	29,43

/1/ The 1-phosphate ester of this diol is said to occur in brain tissue and sea-urchin eggs [33].

continued

Part III. NATURAL ALDITOLS AND INOSITOLS (with Inososes and Inosamines)

	Substance (Synonym)	Chemical Formula	Melting Point °C	Specific Rotation $[\alpha]_D$	Reference
	(A)	(B)	(C)	(D)	(E)
	Inositols				
23	*d*-Bornesitol (a *myo*-inositol monomethyl ether)	$C_7H_{14}O_6$	200	+31.6	20,22
24	*l*-Bornesitol (a *myo*-inositol monomethyl ether)	$C_7H_{14}O_6$	205-206	-32.1	11
25	Conduritol (a 2,3-dehydro-2,3-dideoxyinositol)	$C_6H_{10}O_4$	142-143	None (meso)	30
26	Cordycepic acid (a tetrahydroxycyclohexanecarboxylic acid)[2]	$C_7H_{12}O_6$	....	....	15
27	Dambonitol (a *myo*-inositol dimethyl ether)	$C_8H_{16}O_6$	206	None (meso)	17
28	DL-Inositol	$C_6H_{12}O_6$	253	None (racemic)	53
29	*d*-Inositol	$C_6H_{12}O_6$	....	+60	8
30	*l*-Inositol	$C_6H_{12}O_6$	240	-65	51
31	Laminitol (a *C*-methyl *myo*-inositol)	$C_7H_{14}O_6$	266-269	-3	32
32	Liriodendritol (a *myo*-inositol dimethyl ether)	$C_8H_{16}O_6$	224	-25	40
33	*muco*-Inositol monomethyl ether	$C_7H_{14}O_6$	322-325	....	3
34	*myo*-Inositol (*meso*-Inositol)	$C_6H_{12}O_6$	217-218	None (meso)	35
35	*d*-*myo*-Inosose-1 (a deoxy keto inositol)	$C_6H_{10}O_6$	138-139	+19.6	34
36	Mytilitol (a *C*-methyl *scyllo*-inositol)	$C_7H_{14}O_6$	259	None (meso)	1
37	*neo*-Inosamine-2 (a deoxy amino inositol)	$C_6H_{13}O_5N$	239-241 d.	None (meso)	4
38	*d*-Ononitol (a *myo*-inositol monomethyl ether)	$C_7H_{14}O_6$	172	+6.6	41
39	*d*-Pinitol (a *dextro*-inositol monomethyl ether)	$C_7H_{14}O_6$	186	+65.5	37
40	*l*-Pinitol (a *levo*-inositol monomethyl ether)	$C_7H_{14}O_6$	186	-65	5,42
41	*l*-Quebrachitol (a *levo*-inositol monomethyl ether)	$C_7H_{14}O_6$	190-191	-80.2 [28°]	2,16
42	*d*-Quercitol (a deoxy *dextro*-inositol)	$C_6H_{12}O_5$	235	+24.2	45
43	*d*-Quinic acid (a trideoxy carboxy *dextro*-inositol)	$C_7H_{12}O_6$	164	+44 (*c* 10)	55
44	*l*-Quinic acid (a trideoxy carboxy *levo*-inositol)	$C_7H_{12}O_6$	162	-42.1	23
45	Quinic acid, 5-dehydro-	$C_7H_{10}O_6$	140-142 (138 s.)	-82.4 [28°]	58
46	Scyllitol (*scyllo*-Inositol; Cocositol)	$C_6H_{12}O_6$	352-353	None (meso)	38,44
47	Sequoyitol (a *myo*-inositol monomethyl ether)	$C_7H_{14}O_6$	234-235	None (meso)	50
48	Shikimic acid (a 3,4-anhydro-quinic acid)	$C_7H_{10}O_5$	183-184	-200 [16°]	19
49	Shikimic acid, 5-dehydro-	$C_7H_8O_5$	150-152	-57.5 [28°] (EtOH)	49
50	Streptamine (2,4-diaminodideoxyscyllitol)	$C_6H_{14}O_4N_2$	88, 210-250 d.	None (meso)	27
51	Streptamine, 2-deoxy-	$C_6H_{14}O_3N_2$	....	None (meso)	18,31
52	Streptadine (1,3-Dideoxy-1,3-diguanidino-scyllitol)	$C_8H_{18}N_6O_4$	....	None (meso)	39
53	Viburnitol (a deoxy *levo*-inositol)[3]	$C_6H_{12}O_5$	174	-73.9	26

/2/ Strong evidence that cordycepic acid is really D-mannitol [52]. /3/ Not an enantiomorph of *d*-quercitol; other isomeric relationship is involved.

Contributors: Wolfrom, Melville L.; Maher, George G.; and Pagnucco, Rinaldo C.

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Part IV. NATURAL ALDONIC, URONIC, AND ALDARIC ACIDS

A number of "keto" acids, reported in the literature as stemming from biological systems, have not been included since they are still grossly undefined [4,27].

	Substance (Synonym)	Chemical Formula	Melting Point °C	Specific Rotation $[\alpha]_D$	Reference
	(A)	(B)	(C)	(D)	(E)
	Aldonic Acids				
1	D-Glyceric acid	$C_3H_6O_4$	Gum	Dextro	15
2	L-Glyceric acid	$C_3H_6O_4$	Gum	Levo	15
3	D-Arabinonic acid	$C_5H_{10}O_6$	114-116	+10.5 (*c* 6)	35
4	L-Arabinonic acid	$C_5H_{10}O_6$	118-119	-9.6 → -41.7[1]	32
5	L-Arabinonic-1, 4-lactone	$C_5H_8O_5$	97-99	-72	5
6	D-Ribonic acid	$C_5H_{10}O_6$	112-113	-17.0	22
7	D-Xylonic acid	$C_5H_{10}O_6$	....	-2.9 → +20.1[1]	33
8	L-Xylonic acid	$C_5H_{10}O_6$	....	-91.8[1]	20
9	D-Altronic acid	$C_6H_{12}O_7$	....	+11.5 → +24.8[1] (Ca salt, *N* HCl)	19,34
10	D-Galactonic acid	$C_6H_{12}O_7$	122	-11.2 → +57.6[1]	21,30
11	D-Gluconic acid	$C_6H_{12}O_7$	130-132 (110-112 s.)	-6.7 → +11.9[1]	31
12	L-Gulonic acid	$C_6H_{12}O_7$	Exists only in soln.	[ca. 0°]	8
13	Hexsonic acid, 2-deoxy-D-*arabino*-	$C_6H_{12}O_6$	93-95	+68 (lactone)	14,40
14	2-Hexulosonic acid, D-*arabino*-	$C_6H_{10}O_7$	....	-81.7 (Na salt)	26
15	2-Hexulosonic acid, 3-deoxy-D-*erythro*-	$C_6H_{10}O_6$	....	-29.2 (*c* 6, Ca salt)	25
16	2-Hexulosonic acid, D-*lyxo*-	$C_6H_{10}O_7$	169	-5	12
17	5-Hexulosonic acid, D-*arabino*-	$C_6H_{10}O_7$	108-109	....	3
18	5-Hexulosonic acid, D-*xylo*-	$C_6H_{10}O_7$	....	-14.5	7
19	D-Mannonic acid	$C_6H_{12}O_7$	....	-15.6	23
20	D-Gluconic acid, *O*-β-D-galactopyranosyl-(1 → 4)- (Lactobionic acid)	$C_{12}H_{22}O_{12}$	....	+25.1 (Ca salt)	37
	Uronic Acids				
21	L-Lyxuronic acid	$C_5H_8O_6$	....	....	1,2

/1/ Equilibrates with the lactone.

continued

Part IV. NATURAL ALDONIC, URONIC, AND ALDARIC ACIDS

	Substance (Synonym)	Chemical Formula	Melting Point °C	Specific Rotation $[\alpha]_D$	Reference
	(A)	(B)	(C)	(D)	(E)
	Uronic Acids				
22	β-D-Galacturonic acid	$C_6H_{10}O_7$	160	+27 → +55.6	11
23	α-D-Galacturonic acid·monohydrate	$C_6H_{12}O_8$	159-160 (110-115 s.)	+97.9 → +50.9	11
24	D-Galacturonic acid, 2-amino-2-deoxy-	$C_6H_{11}O_6N$	160 d.	+84.5 (pH 2 HCl)	17,18
25	β-D-Glucuronic acid	$C_6H_{10}O_7$	156	+11.7 → +36.3	39
26	D-Glucuronic acid, 2-amino-2-deoxy-	$C_6H_{11}O_6N$	120-172 d.	+55	16,41
27	D-Glucuronic acid, 3-*O*-methyl-	$C_7H_{12}O_7$	Syrup	+6	10,24
28	L-Guluronic acid	$C_6H_{10}O_7$	....	....	6,13
29	L-Iduronic acid	$C_6H_{10}O_7$	....	+30	9
30	β-D-Mannuronic acid	$C_6H_{10}O_7$	165-167	-47.9 → -23.9	36
31	α-D-Mannuronic acid·monohydrate	$C_6H_{12}O_8$	110 s., 120-130 d.	+16 → -6.1 (*c* 6.8)	36
	Aldaric Acids				
32	D-Tartaric acid	$C_4H_6O_6$	170	-15	28
33	L-Tartaric acid	$C_4H_6O_6$	170	+15 [15°]	38
34	L-Malic acid	$C_4H_6O_5$	100	-2.3 (*c* 8.4)	29

Contributors: Wolfrom, Melville L.; Maher, George G.; and Pagnucco, Rinaldo G.

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continued

98. CARBOHYDRATES: PHYSICAL AND CHEMICAL CHARACTERISTICS

Part V. NATURAL CARBOHYDRATE PHOSPHATE ESTERS

Wavelength (column F): D = the sodium D line, 5896 Ångstrom units.

	Substance (Synonym)	Hydrolysis Constant[1] k x 10^3	Temp. °C	Medium	Specific Rotation $[\alpha]_D$	Wave-length	Compound	Concentration	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
1	Dihydroxyacetone phosphate	33.7	100	*N* HCl	....	....	....	....	34
2	D-Glyceraldehyde 3-phosphate	37.5	100	*N* HCl	+12	D	Free acid	....	19,34,54
3	D-Glyceric acid 2-phosphate	.....	....	....	+24.3, +13 -68, +5	D D	Free acid Free acid	(*N* HCl) (NH_4 molybdate)	6,35 6,55
4	D-Glyceric acid 3-phosphate	1.8[2]	125	*N* HCl	-14.5, +14 -725 +5	D D D	Ba salt Ba salt	(*N* HCl) (Molybdate ion) (NH_4 molybdate)	6,35 56 6
5	Glyceric acid phosphate, 2-deoxy-	15[2]	90	*N* HCl	....	....	....	....	8
6	D-Glyceric acid 1,3-diphosphate	26	38	Water	Very small	....	....	....	58
7	D-Glyceric acid 2,3-diphosphate	.....	....	....	-2, -4 -4, -5, +4.6	D D	Ba salt Na salt	6-17 (*N* HNO_3) 6-28	4,23 4,23,78
8	L-Glycerol 1-phosphate (α-L-Glycerophosphate; L-Glycerin 1-phosphate)	0.15	80	Water pH 6.3	+1.0	D	Ag salt	6.5	5,36,87
9	D-Erythritol 4-phosphate	.....	....	....	-2.6	D	Free acid	....	73
10	D-Erythrose 4-phosphate	.....	....	....	0	D	Free acid	....	7
11	L-Erythrulose 1-phosphate	10[2]	100	*N* HCl	....	....	....	....	15
12	D-Arabinose 5-phosphate	<3[2]	100	*N* H_2SO_4	....	....	....	....	86
13	L-Arabinofuranose 1-phosphate	.....	....	....	+16.9	D	Free acid	....	93
[illegible]	-Arabinopyranose 1-phosphate	.....	....	....	+48.2	D	Ba salt	....	93
	entose 1-phosphate, α-D-*erythro*-	.....	....	....	+34.5	D	Cyclohexylamine salt	....	48
[illegible]	Pentose 1-phosphate, β-D-*erythro*-	13-17[2]	....	Acetate buffer pH 4.5	-15.8	D	Cyclohexylamine salt	....	20,48,88
17	Pentose 5-phosphate, β-D-*erythro*-	50[2]	100	*N* HCl	+19	D	Free acid	0.47	48,65
18	Pentose 1,5-diphosphate, D-*erythro*-	>3 <5[3]	100 100	pH 4 *N* HCl	....	....	....	....	83 83
19	D-Ribitol 5-phosphate (L-Ribitol 1-phosphate)	<5[2]	100	*N* HCl	....	....	....	....	3
20	α-D-Ribofuranose 1-phosphate	1.25[2]	20	0.01 *N* HCl	+40.3	D	Dicyclohexylamine salt	(Water)	84,92,93
21	β-D-Ribofuranose 1-phosphate	0.63[2] 1200	20 25	0.01 *N* HCl 0.5 *N* HCl	-9.3 -13.6 -12.9	D D D	Ba salt Dicyclohexylamine salt Free acid	.... (Ethanol)	92,93 84 32,41
22	D-Ribopyranose 1-phosphate	1.25[2]	20	0.1 *N* HCl	-47.1	D	Ba salt	(5% acetic acid)	92,93
23	D-Ribose 2-phosphate	.....	....	....	-6.8	D	Ba salt	....	33
24	D-Ribose 3-phosphate	.....	....	....	-6.8	D	Ba salt	....	33
		4.5	100	0.25 *N* HCl	-9.7	D	Na salt	....	1,44
25	D-Ribose 5-phosphate	0.5	100	0.25 *N* HCl	+6.0 +18±2	D D	Ba salt Free acid	.... (0.2-1 *N* HCl)	1,46 26,57
26	α-D-Ribose 1,5-diphosphate	1.6	70	0.01 *N* HCl	+20.8	D	Tetracyclohexylamine salt	0.43	85
27	D-Ribose 5-phosphate 1-pyrophosphate	30[4]	65	pH 4	....	....	....	....	37

/1/ For the first ester group that lies farthest in the sugar carbon-chain structure from the primary hydroxyl carbon (or asymmetric center) which determines the D or L configuration of the parent sugar. /2/ Calculated by the contributors from data of the original investigator, using k = 0.30/time in minutes for 50% hydrolysis. /3/ For the second ester group. /4/ For the pyrophosphate group.

continued

98. CARBOHYDRATES: PHYSICAL AND CHEMICAL CHARACTERISTICS

Part V. NATURAL CARBOHYDRATE PHOSPHATE ESTERS

	Substance (Synonym)	Hydrolysis Constant[1] k x 10^3	Temp. °C	Medium	Specific Rotation $[\alpha]_D$	Wave-length	Compound	Concentration	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
28	D-Ribulose 5-phosphate	5	100	*N* HCl	-29	D	Free acid	(0.2 *N* HCl)	27,30
29	L-Ribulose 5-phosphate	<0.5	90	*N* H_2SO_4	+28	D	Free acid	(0.2 *N* HBr)	75,76
30	D-Ribulose 1, 5-diphosphate	15[5]	100	*N* H_2SO_4	....	....	....	....	29
31	D-Xylose 5-phosphate	4	100	*N* HCl	+3.2	D	Na salt	....	45
					+5	D	Ba salt	....	45
32	D-Xylulose phosphate	86	100	*N* HCl	....	....	....	....	22,77
33	D-Fructose 1-phosphate	70	100	*N* HCl	-64.2	5461	Free acid	11.3	82
					-39	5461	Ba salt	6.1	82
34	D-Fructose 6-phosphate	4.4	100	*N* HCl	+3.6	D	Ba salt	10	59,69
35	D-Fructose 1, 6-diphosphate	52	100	*N* HCl	+4.1	D	Free acid	13.6	50,59
36	L-Fuculose 1-phosphate	60	100	*N* HCl	-2.3	D	Ba salt	5.1	24
37	α-D-Galactose 1-phosphate	5.9	37	0.25 *N* HCl	+108	D	K salt	2.6	38,39
					+148	D	Free acid	1.7 (0.2 *N* HCl)	38,39
					+92; +113	D; 5461	Ba salt	....	38,39
					+78.5	D	Dicyclohexylamine salt	(pH 7.8)	64
38	β-D-Galactose 1-phosphate	5.6	37	0.25 *N* HCl	+31.3	D	Ba salt·$3H_2O$	1.2	66
					+21	D	Dicyclohexylamine salt	(pH 7.8)	64
39	D-Galactose 1-phosphate, 2-amino-2-deoxy-	.....	....	....	178	D	N-Acetyl derivative	....	13,14
40	D-Galactose 6-phosphate	.....	....	....	+25.2	D	Ba salt	[16°]	31,80, 81
					-11.9	D	CH_3 β-D-galactoside dicyclohexylamine salt	0.5	79
41	D-Galactose 6-phosphate, 2-amino-2-deoxy-	8[2]	110	6 *N* HCl	48.4	D	N-Acetyl derivative	(0.05 *M* Na acetate)	18,47
42	D-Gluconic acid 6-phosphate	0.21	100	*N* HCl	+0.2	5461	Free acid	....	61,68
					+18	5461	Free acid lactone	....	68
43	D-Glucose 1-phosphate, 2-amino-2-deoxy-	60[2]	100	*N* $HClO_4$	+79	D	N-Acetyl derivative, α-form	....	11,51
					-1.6	D	N-Acetyl derivative, β-form	....	9
44	D-Glucose 6-phosphate, 2-amino-2-deoxy-	0.06[2]	100	*N* HCl	+54	D	Free acid	....	2
					+29.5	D	N-Acetyl derivative	8 (0.5 *M* Na acetate)	18
45	α-D-Glucose 1-phosphate	1.3	37	0.25 *N* HCl	+118	D	Free acid	....	16
		5[6]	33	*N* HCl	+0.5	D	Dibrucine salt·$8H_2O$	....	91
					+75.5	D	Ba salt	....	16
					+78; +90	D; 5461	K salt·$2H_2O$	....	90
					+64	D	Dicyclohexylamine salt	(pH 7.8)	64
46	β-D-Glucose 1-phosphate	15[6]	33	*N* HCl	-20	D	Dibrucine salt·$10H_2O$	....	91
					+7.3	D	Dicyclohexylamine salt	....	64
47	D-Glucose 6-phosphate	0.23	100	*N* HCl	+35.7; +41.4	D; 5461	Free acid	....	68,69
					+18; +21.2	D; 5461	Ba salt	8.4	68,69
					+21.2	D	K salt	....	40

/1/ For the first ester group that lies farthest in the sugar carbon-chain structure from the primary hydroxyl carbon (or asymmetric center) which determines the D or L configuration of the parent sugar. /2/ Calculated by the contributors from data of the original investigator, using k = 0.30/time in minutes for 50% hydrolysis. /5/ Both groups hydrolyze equally. /6/ Constants determined on the brucine salt.

continued

Part V. NATURAL CARBOHYDRATE PHOSPHATE ESTERS

	Substance (Synonym)	Hydrolysis Constant[1] $k \times 10^3$	Temp. °C	Medium	Specific Rotation $[\alpha]_D$	Wavelength	Compound	Concentration	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
	D-Glucose 6-phosphate (*See* preceding page)	0.23	100	*N* HCl	+61	D	CH_3 α-D-glucoside dicyclohexylamine salt	....	79
48	D-Glucose phosphate, 2-amino-3-*O*-(2-carboxyethyl)-2-deoxy- (Muramic acid phosphate)	0.8[2]	100	6 *N* HCl	....	....	....	....	47
49	α-D-Glucose 1,6-diphosphate	0.78	30	*N* H_2SO_4	+83±4	D	Free acid	0.2	63
50	β-D-Glucose 1,6-diphosphate	3.15	30	*N* H_2SO_4	-19±2	D	Free acid	0.2	63
51	D-Glucuronic acid 1-phosphate	.....	....	....	+53.6	D	Tri K salt form	[19°]	10
52	2-Hexulosonic acid 6-phosphate, 3-deoxy-D-*erythro*-[7]	5-6[2]	100	*N* HCl	....	....	....	....	49
53	*myo*-Inositol 1-phosphate (*myo*-Inositol 3-phosphate)	0.99	100	pH 2.0	+3.4	D	Dicyclohexylamine salt	(pH 9)	62
					-9.8	D	Dicyclohexylamine salt	(pH 2)	62
54	*myo*-Inositol 2-phosphate	.....	....	....	None (meso)	....	....	....	62
55	D-Mannitol 1-phosphate	<0.5[2]	100	*N* HCl	....	....	....	....	89
56	D-Mannose 6-phosphate	0.29	100	*N* HCl	+15.1	5461	Free acid	1.7	69
					+3.5	5461	Ba salt	0.7	41
57	Shikimic acid 5-phosphate	.....	....	....	-107.6	D	K salt·H_2O	[29°]	88
58	L-Sorbose 1-phosphate	60[2]	100	*N* HCl	-16.5	D	Mono K salt	....	25,52
					-7.2	D	Ba salt·$2H_2O$	(0.1 *N* HCl)	52
59	2-Heptulose 7-phosphate, D-*altro*- (Sedoheptulose 7-phosphate)	0.28[2]	100	*N* H_2SO_4	....	....	....	....	28
60	2-Heptulose 1,7-diphosphate, D-*altro*- (Sedoheptulose 1,7-diphosphate)	20[4]	100	*N* H_2SO_4	....	....	....	....	28
		0.28[3]	100	*N* H_2SO_4	....	....	....	....	28
61	Unidentified ketoheptose monophosphate[8]	4	100	*N* HCl	+8	5461	Ba salt	....	70
62	α,α'-Diglycerophosphate	150[2]	100	*N* HNO_3	....	....	....	....	53
63	1-Glycerophosphoryl-*myo*-inositol	15[2]	100	*N* HCl	-14	D	Cyclohexylamine salt	6 (pH 3.5)	43
64	α-Lactose 1-phosphate	2[2]	37	*N* HCl	73.3	D	Ba salt	....	21,71, 72
65	β-Lactose 1-phosphate	6[2]	37	*N* HCl	24.8	D	Ba salt·$5H_2O$	....	21,71, 72
66	Sucrose 1-phosphate	5.9[2]	100	*N* H_2SO_4	....	....	....	....	42
67	Trehalose phosphate	0.16	....	....	+185	D	....	(0.1 *N* HCl)	12,67
					+132	5461	Ba salt	....	12,67

/1/ For the first ester group that lies farthest in the sugar carbon-chain structure from the primary hydroxyl carbon (or asymmetric center) which determines the D or L configuration of the parent sugar. /2/ Calculated by the contributors from data of the original investigator, using k = 0.30/time in minutes for 50% hydrolysis. /3/ For the second ester group. /4/ For the pyrophosphate group. /7/ D-*arabino*-Hexulosonic acid is also found in natural systems as a phosphate, but characterization constants are unknown [17]. /8/ A D-*arabino*-3-hexulose phosphate and a *manno*-heptulose phosphate are known in nature, but their characterization constants are unknown [60,74].

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continued

98. CARBOHYDRATES: PHYSICAL AND CHEMICAL CHARACTERISTICS

Part V. NATURAL CARBOHYDRATE PHOSPHATE ESTERS

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Part VI. NATURAL OLIGOSACCHARIDES

Substances have been arranged in groups (disaccharides, trisaccharides, etc.) according to increasing carbon atom content in the parent component monosaccharide units. Within groups, substances are arranged alphabetically according to the name of the initial glycosyl monosaccharide unit in the oligosaccharide. **Substance** (column A): Gal = galactose; Man = mannose; Xyl = xylose; G = glucose; Fru = fructose; Fuc = fucose; *p* = pyranose; *f* = furanose.

	Substance (Synonym)	Chemical Formula	Melting Point °C	Specific Rotation $[\alpha]_D$	Reference
	(A)	(B)	(C)	(D)	(E)
1	*O*-α-D-Gal*p*-(1 → 1)-D-glycerol	$C_9H_{18}O_8$	150-152	+155	111
2	*O*-β-D-Gal*p*-(1 → 1)-D-glycerol	$C_9H_{18}O_8$	139-140	+3.8	13
3	*O*-α-D-Gal*p*-(1 → 2)-glycerol (Floridoside)	$C_9H_{18}O_8$	86-87, 128	+151, +165	14, 70, 84
4	*O*-β-D-Gal*p*-(1 → 1)-L-glycerol	$C_9H_{18}O_8$	131.5-133	+159	111
5	*O*-α-D-Man*p*-(1 → ?)-L-glyceric acid	$C_9H_{16}O_9$	88-89	+105 [15°]	15
6	*O*-D-Xyl*p*-(1 → 1)-D-G*p*[1]	$C_{11}H_{20}O_{10}$	Amorphous	-36.5	68
7	*O*-D-Xyl*p*-(1 → 6)-D-G*p*	$C_{11}H_{20}O_{10}$	208	+24.1 → -3.3	26, 94
8	*O*-β-D-Gal*p*-(1 → 3)-D-arabinitol	$C_{11}H_{22}O_{10}$	138-139	-81	41
9	*O*-D-Fru*f*-(2 → 2)-D-Fru*f* (Alliuminoside)	$C_{12}H_{22}O_{11}$	92-93	-23.8	78, 79
10	*O*-D-Fru*f*-(2 → 1)-D-Fru*f* (Inulobiose)	$C_{12}H_{22}O_{11}$	....	-26.4	81, 82
11	*O*-D-Fru*f*-(2 → ?)-D-Fru*f* (Sogdianose)	$C_{12}H_{22}O_{11}$	156-158	-16.4	78, 79
12	*O*-D-Fru*f*-(2 → ?)-D-G*p*	$C_{12}H_{22}O_{11}$	....	-21	94
13	*O*-β-D-Fru*f*-(2 → 1)-α-D-G*p* (Sucrose)	$C_{12}H_{22}O_{11}$	188, 170[2]	+66.5 (*c* 26)	9
14	*O*-α-D-Gal*p*-(1 → 6)-D-Gal*p* (Swietenose)	$C_{12}H_{22}O_{11}$	....	+149	30, 31, 91
15	*O*-β-D-Gal*p*-(1 → 4)-α-D-G*p* (α-Lactose)	$C_{12}H_{22}O_{11} \cdot H_2O$	202	+83.5 → +52.6	21, 90
16	*O*-β-D-Gal*p*-(1 → 4)-β-D-G*p* (β-Lactose)	$C_{12}H_{22}O_{11}$	252	+34.2 → +53.6	21, 89, 90
17	*O*-β-D-Gal*p*-(1 → 6)-D-G*p* (Allolactose)	$C_{12}H_{22}O_{11}$	165	+25	66, 67
18	*O*-D-Gal-(? → ?)-D-G (Gynolactose)	$C_{12}H_{22}O_{11}$	205	-27	66, 67
19	*O*-α-D-Gal*p*-(1 → 6)-β-D-G*p* (β-Melibiose)	$C_{12}H_{22}O_{11} \cdot 2H_2O$	82-85	+111.7 → +129.5	9
20	*O*-α-D-Gal*p*-(1 → 6)-β-D-glucitol (Melibiitol)	$C_{12}H_{24}O_{11}$	173-175	+111	4
21	*O*-α-D-Gal*p*-(1 → 1)-*myo*-inositol	$C_{12}H_{22}O_{11} \cdot 2H_2O$	220-222	+135.6	12
22	*O*-D-Gal*p*-(1 → ?)-mannitol	$C_{12}H_{24}O_{11}$	162	-55.5	69
23	*O*-α-D-G*p*-(1 → 3)-D-Fru (Turanose)	$C_{12}H_{22}O_{11}$	157	+22 → +75.3	29
24	*O*-α-D-G*p*-(1 → 4)-D-Fru*f* (Maltulose)	$C_{12}H_{22}O_{11}$	113-115 d. (monohydrate)	58 → 64	28, 103
25	*O*-α-D-G*p*-(1 → 6)-D-Fru*f* (Palatinose; Isomaltulose)	$C_{12}H_{22}O_{11}$	....	+97.2	4, 99
26	*O*-α-D-G*p*-(1 → 1)-α-D-G*p* (Trehalose)	$C_{12}H_{22}O_{11} \cdot 2H_2O$	97, 203	+178.3 (*c* 7)	9, 92
27	*O*-α-D-G*p*-(1 → 2)-D-G*p* (Kojibiose)	$C_{12}H_{22}O_{11}$	175	+135	86, 87, 95, 96
28	*O*-α-D-G*p*-(1 → 3)-D-G*p* (Nigerose; Sakebiose)	$C_{12}H_{22}O_{11}$	....	+145	23, 95, 96
29	*O*-β-D-G*p*-(1 → 3)-α-D-G*p* (α-Laminaribiose)	$C_{12}H_{22}O_{11}$	160-163, 202-205	+23.4 → +19	8, 100
30	*O*-β-D-G*p*-(1 → 3)-β-D-G*p* (β-Laminaribiose)	$C_{12}H_{22}O_{11}$	188-192	+7.5 → +20.8	4, 16
31	*O*-β-D-G*p*-(1 → 4)-β-D-G*p* (β-Cellobiose)	$C_{12}H_{22}O_{11}$	225	+14.2 → +34.6 (*c* 8)	65
32	*O*-α-D-G*p*-(1 → 4)-α-D-G*p* (α-Maltose)	$C_{12}H_{22}O_{11}$	108	+173	22
33	*O*-α-D-G*p*-(1 → 4)-β-D-G*p* (β-Maltose)	$C_{12}H_{22}O_{11} \cdot H_2O$	102-103	+112.5 → +130	22
34	*O*-α-D-G*p*-(1 → 6)-D-G*p* (Isomaltose)	$C_{12}H_{22}O_{11}$	....	+103.2	95, 96, 109
35	*O*-α-D-G*p*-(1 → 1)-α-D-GN (Trehalosamine)	$C_{12}H_{23}NO_{10}$	....	+176 (*c* 0.02, dil. HCl)	2, 3
36	*O*-β-D-G*p*-(1 → 1)-mannitol	$C_{12}H_{21}O_{11}$	140-141	-18.0	42
37	*O*-α-D-Gal*p*-(1 → 6)-*O*-β-D-Gal*p*-(1 → 1)-glycerol	$C_{15}H_{28}O_{13}$	196-198	+90	104
38	*O*-α-D-Man*p*-(1 → 3)-*O*-α-D-Gal*p*-(1 → 2)-glycerol	$C_{15}H_{28}O_{13}$	....	....	43
39	*O*-D-Fru*f*-(2 → ?)-*O*-D-Fru*f*-(2 → 2)-D-Fru*f* (Polygontin)	$C_{18}H_{32}O_{16}$	207-208	-52.9	78, 79

/1/ The free sugar does not exist in nature, but its dibenzoyl derivatives do. /2/ Compound crystallizes in one of two forms, depending on the solvent used.

continued

Part VI. NATURAL OLIGOSACCHARIDES

	Substance (Synonym)	Chemical Formula	Melting Point °C	Specific Rotation $[\alpha]_D$	Reference
	(A)	(B)	(C)	(D)	(E)
40	*O*-D-Fru*f*-(2 → ?)-*O*-D-Fru*f*-(2 → 2)-D-Fru*f* (Trifructan)	$C_{18}H_{32}O_{16}$	...	-22.3	81,82
41	*O*-D-Fru*f*-(2 → ?)-*O*-D-Fru*f*-(2 → 1)-D-G*p*	$C_{18}H_{32}O_{16}$	...	+22	5,24
42	*O*-β-D-Fru*f*-(2 → 6)-*O*-α-D-G*p*-(1 → 2)-β-D-Fru*f* (Neokestose)	$C_{18}H_{32}O_{16}$	...	+15	24
43	*O*-L-Fuc-(1 → 2)-*O*-D-Gal*p*-(1 → 4)-β-D-G*p*	$C_{18}H_{32}O_{15}$	230-231 d.	-57.5(*c* 0.2)	37,49
44	*O*-D-Gal-(? → ?)-*O*-D-Fru-(? → ?)-D-Fru (Labiose)	$C_{18}H_{32}O_{16}\cdot 3H_2O$	126 s., b.p. 205	+136.7	76,77
45	*O*-α-D-Gal*p*-(1 → 6)-*O*-β-D-Fru*f*-(1 → 6)-α-D-G*p* (Planteose)	$C_{18}H_{32}O_{16}\cdot 2H_2O$	123-124	+125.2	19,97,98
46	[*O*-α-D-Gal*p*-(1 → 6)-]$_2$α-D-G*p* (Manninotriose)	$C_{18}H_{32}O_{16}$	150 amorphous	+167	88
47	*O*-α-D-Gal*p*-(1 → 2)-*O*-α-D-G*p*-(1 → 2)-β-D-Fru*f* (Umbelliferose)	$C_{18}H_{32}O_{16}$	...	+125	105
48	*O*-α-D-Gal*p*-(1 → 3)-*O*-α-D-G*p*-(1 → 2)-β-D-Fru*f*	$C_{18}H_{32}O_{16}$	...	...	45
49	*O*-α-D-Gal*p*-(1 → 6)-*O*-α-D-G*p*-(1 → 2)-β-D-Fru*f* (Raffinose)	$C_{18}H_{32}O_{16}\cdot 5H_2O$	80, 118-120	+105, +123.1	44,71
50	*O*-D-Gal*p*-(1 → 4)-*O*-D-G*p*-(1 → ?)-L-Fuc	$C_{18}H_{32}O_{15}$	...	...	49
51	*O*-α-D-G*p*-(1 → 2)-*O*-β-D-Fru*f*-(1 → 2)-β-D-Fru*f* (Isokestose)	$C_{18}H_{32}O_{16}$	148, 189-190	+29.3	6,7,73
52	*O*-α-D-G*p*-(1 → 2)-*O*-β-D-Fru*f*-(6 → 2)-β-D-Fru*f* (Kestose)	$C_{18}H_{32}O_{16}$	145	+28	1,18
53	*O*-α-D-G*p*-(1 → 3)-*O*-β-D-Fru*f*-(2 → 1)-α-D-G*p* (Melezitose)	$C_{18}H_{32}O_{16}\cdot 2H_2O$	153-154	+88.2	34,93
54	*O*-α-D-G*p*-(1 → 4)-*O*-α-D-G*p*-(1 → 2)-β-D-Fru*f* (Erlose)	$C_{18}H_{32}O_{16}$	...	+121.8	102,108
55	*O*-β-D-G*p*-(1 → 6)-*O*-α-D-G*p*-(1 → 2)-β-D-Fru*f* (Gentianose)	$C_{18}H_{32}O_{16}$	210	+33.4	10,47
56	[*O*-α-D-G*p*-(1 → 4)-]$_2$α-D-G*p*- (Maltotriose)	$C_{18}H_{32}O_{16}$	Amorphous	+160	85,110
57	*O*-D-G*p*-(1 → 1)-*O*-D-G*p*-(1 → 6)-D-mannitol	$C_{18}H_{34}O_{16}$	...	-14	34
58	*N*-Acetylneuraminic acid-(1 → ?)-*O*-β-D-Gal*p*-(1 → 4)-β-D-G*p* (Neuraminlactose)	...	...	10-26	75
59	Fructo-tetraose (Veronicin; Campanulin)	$C_{24}H_{42}O_{21}$	170, 188	-23, -29.4 [30°]	57,59,61,62
60	*O*-D-Fru*f*-(2 → 1)-*O*-D-Fru*f*-(2 → 6)-*O*-D-G*p*-(2 → 2)-D-Fru*f* (Neobifurcose)	$C_{24}H_{42}O_{21}$	...	+14.4	74
61	*O*-L-Fuc-(1 → ?)-*O*-L-Fuc-(1 → 3)-*O*-β-D-Gal*p*-(1 → 4)-D-G*p* (Lactodifucotetraose)	$C_{24}H_{42}O_{19}$	...	-106	38
62	*O*-L-Fuc-(1 → ?)-*O*-β-L-Fuc-(1 → ?)-*O*-β-D-Gal*p*-D-G*p*	$C_{24}H_{42}O_{19}$	...	-17.1	48,50,51
63	*O*-D-Gal*p*-(1 → ?)-*O*-D-Gal*p*-(1 → ?)-*O*-D-Fru*f*-(2 → 1)-D-G*p* (Sesamose)[3]	$C_{24}H_{42}O_{21}$	...	...	25
64	[*O*-α-D-Gal*p*-(1 → 6)-]$_2$*O*-α-D-G*p*-(1 → 2)-β-D-Fru*f* (Stachyose, Manneotetrose)	$C_{24}H_{42}O_{21}$	170 (140 s.)	+146.3	20,64,88
65	*O*-α-D-Gal*p*-(1 → 6)-*O*-α-D-G*p*-(1 → 2)-*O*-β-D-Fru*f*-(1 → 1)-α-D-Gal*p* (Lychnose)	$C_{24}H_{42}O_{21}$	...	+153 to +154	106
66	*O*-α-D-Gal*p*-(1 → 6)-*O*-α-D-G*p*-(1 → 2)-*O*-β-D-Fru*f*-(3 → 1)-α-D-Gal*p* (Isolychnose)	$C_{24}H_{42}O_{21}$	...	...	107
67	*O*-β-D-Gal*p*-(1 → 3)-*O*-β-D-G*p*NAc-(1 → 3)-*O*-β-D-Gal*p*-(1 → 4)-D-G*p* (Lacto-*N*-tetraose)	$C_{26}H_{45}NO_{21}$	200-205 d.	+38	35
68	*O*-α-D-G*p*-(1 → 2)-[*O*-β-D-Fru*f*-(6 → 2)-]$_2$β-D-Fru*f*-	$C_{24}H_{42}O_{21}$	...	-7	72
69	*O*-D-G*p*-(1 → 2)-*O*-D-Fru*f*-(2 → 6)-*O*-D-Fru*f*-(1 → 2)-D-Fru*f*	$C_{24}H_{42}O_{21}$	156	+8	73
70	*O*-D-G*p*-(1 → ?)-[D-Fru*f*-]$_2$D-Fru*f*	$C_{24}H_{42}O_{21}$	...	+15.6	80,83
71	[*O*-α-D-G*p*-(1 → 4)-]$_2$*O*-α-D-G*p*-(1 → 2)-β-D-Fru*f* (Maltosylsucrose)	$C_{27}H_{42}O_{21}$	...	...	108
72	[*O*-α-D-G*p*-(1 → 4)-]$_3$D-G*p* (Maltotetraose)	$C_{24}H_{42}O_{21}$	...	+176.4	101
73	Scorodose	$C_{24}H_{42}O_{21}$	200 amorphous	-41.5	32,33
74	Fructo-pentaose	$C_{30}H_{52}O_{26}$	...	+8	72
75	*O*-D-G*p*-(1 → 2)-*O*-D-Fru*f*-(2 → 6)-[*O*-D-Fru*f*-(1 → 2)-]$_2$D-Fru*f*	$C_{30}H_{52}O_{26}$	...	...	73

/[3]/ The evidence for this compound is based on paper chromatographic and methylation studies.

continued

98. CARBOHYDRATES: PHYSICAL AND CHEMICAL CHARACTERISTICS

Part VI. NATURAL OLIGOSACCHARIDES

	Substance (Synonym)	Chemical Formula	Melting Point °C	Specific Rotation $[\alpha]_D$	Reference
	(A)	(B)	(C)	(D)	(E)
76	*O*-α-L-Fuc*p*-(1→2)-*O*-β-D-Gal*p*-(1→3)-*O*-β-D-G*p*NAc-(1→3)-*O*-β-D-Gal*p*-(1→4)-D-G*p* (Lacto-*N*-fucopentaose I)	$C_{32}H_{55}NO_{25}$	216	-11 → -16.3	36
77	*O*-α-L-Fuc*p*-(1→4)-*O*-β-D-Gal*p*-(1→3)-*O*-β-D-G*p*NAc-(1→3)-*O*-β-D-Gal*p*-(1→4)-D-G*p* (Lacto-*N*-fucopentaose II)	$C_{32}H_{55}NO_{25}$	213-215	-28 → +30.4	39
78	[*O*-α-D-Gal*p*-(1→6)-]$_3$*O*-α-D-G*p*-(1→2)-β-D-Fru*f* (Verbascose)	$C_{30}H_{52}O_{26}$	219-220, 253	+169.9	11,54,55
79	*O*-D-G*p*-(1→2)-*O*-D-Fru*f*-(2→6)-[*O*-D-Fru*f*-(1→2)-]$_2$D-Fru*f*	$C_{30}H_{52}O_{26}$	....	-3.5	73
80	*O*-α-D-G*p*-(1→2)-[*O*-β-D-Fru*f*-(6→2)-]$_3$β-D-Fru*f*	$C_{30}H_{52}O_{26}$	....	-11.2	72
81	*O*-α-L-Fuc*p*-(1→4)-*O*-β-D-Gal*p*-(1→3)-*O*-β-D-G*p*NAc-(1→3)-*O*-β-D-Gal*p*-(1→4)-*O*-α-L-Fuc*p*-(1→3)-D-G*p* (Lacto-*N*-difucohexaose II)	$C_{38}H_{65}NO_{29}$	218-220 d.	-68.8	40
82	[*O*-D-Gal*p*-]$_4$*O*-D-Gal*p*-(1→2)-D-Fru*f* (Lycopose)	$C_{36}H_{62}O_{31}$	270	+187	56,63
83	Fructo-hexaose	$C_{36}H_{62}O_{31}$	178	-41	58,60
84	[*O*-α-D-Gal*p*-(1→6)-]$_4$*O*-α-D-G*p*-(1→2)-β-D-Fru*f* (Ajugose)	$C_{36}H_{62}O_{31}\cdot 6H_2O$	204-205	+163	27
85	*O*-α-D-G*p*-(1→2)-[*O*-β-D-Fru*f*-(6→2)-]$_4$-β-D-Fru*f*	$C_{36}H_{62}O_{31}$	....	-19	72
86	*O*-D-G*p*-(1→?)-[*O*-D-Fru*f*-]$_4$D-Fru*f*	$C_{36}H_{62}O_{31}$	....	-5.3	80,83
87	Fructo-heptaose	$C_{42}H_{72}O_{36}$	....	-35.7	52,53
88	[*O*-α-D-Gal*p*-(1→6)-]$_5$*O*-α-D-G*p*-(1→?)-β-D-Fru*f*	$C_{42}H_{72}O_{36}$	246-248	+168	27
89	[*O*-α-D-Gal*p*-(1→6)-]$_4$*O*-α-D-G*p*-(1→2)-*O*-β-D-Fru*f*-(3→1)-*O*-α-D-Gal*p*	$C_{42}H_{72}O_{36}$	....	....	17
90	Dilacto-*N*-tetraose	$C_{52}H_{88}N_2O_{41}$	....	....	46
91	[*O*-α-D-Gal*p*-(1→6)-]$_6$*O*-α-D-G*p*-(1→?)-β-D-Fru*f*	$C_{48}H_{82}O_{41}$	267-268	+168	27
92	Difucolacto-*N*-tetraose	C_6[illegible]$_{108}N_2O_{49}$	....	....	46

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Melting Point (columns C and K): d. = decomposes. **Solubility** (columns E-G): abs. = absolute; acet. = acetone; bz. =
sl. = slightly; v. = very.

	Glycoside	Chemical Formula	Melting Point °C	Specific Rotation $[\alpha]_D$	Solubility: H_2O	Solubility: Alcohol	Solubility: Other	Occurrence
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
1	Absinthin	$C_{30}H_{40}O_8$	68	.....	sl. s.	s.	s. bz., chl., eth., NaOH	Wormwood
2	Aloin	Mixture	....	.....	s.	s.	sl. s. chl., eth.	*Aloe* spp.
3	Amygdalin	$C_{20}H_{27}O_{11}N$	220[1]	-42	8.3 g/100 ml (h.)	sl. s.	i. eth.	Almonds
4	Apiin	$C_{26}H_{42}O_{10}$	228[1]	.....	s. h.	sl. s. h.	i. eth.	Celery; parsley
5	Arbutin	$C_{12}H_{16}O_7$	195-200	-64	12.5 g/100 ml	7.7 g/100 ml	i. chl., CS_2, eth.	Leaves of cranberry, pear tree
6	Barbaloin	$C_{20}H_{18}O_8$	148	.....	s.	s.	sl. s. eth.	*Aloe* spp.
7	Bryonin	$C_{48}H_{66}O_{18}$	208	.....	sl. s.	s.	i. chl., eth.	*Bryonia alba*
8	Carminic acid	$C_{22}H_{20}O_{13}$	136 d.	.....	s.	s.	s. eth., NaOH; i. chl.	Cochineal
9	Coniferin	$C_{16}H_{22}O_8$	185	-68	0.5 g/100 ml	sl. s.	i. eth.	Conifers; sugar beet
10	Convallatoxin	$C_{29}H_{42}O_{10}$	247	0	0.05 g/100 ml	s.	sl. s. chl., eth.	Lily of the valley
11	Convolvulin	$C_{54}H_{96}O_{27}$	155-168	.....	sl. s.	s.	s. acet.; i. eth.	Jalap resin, Canadian hemp
12	Crocin	$C_{44}H_{64}O_{26}$	186 d.[1]	.....	sl. s.	sl. s.	i. chl., eth.	Saffron, crocus, gardenia
13	Cymarin	$C_{30}H_{44}O_9$	139	+35	s.	....	s. chl., me. al.	*Apocynum* & *Strophanthus* spp.
14	Daphnin	$C_{15}H_{16}O_9$	125 d.[1]	-115	sl. s.	s.	s. NaOH; i. eth.	*Daphne* spp.
15	Diginin	$C_{28}H_{40}O_7$	155-183	-176	i.	....	s. CCl_4, chl.; sl. s. eth.	Leaves of *Digitalis purpurea*
16	Digitonin	$C_{55}H_{90}O_{29}$	235 d.[1]	-54	s.	1.8 g/100 ml (abs.)	i. chl., eth.	Seeds of *Digitalis purpurea*
17	Digitoxin	$C_{41}H_{64}O_{13}$	256	+4.8	0.001 g/100 ml	1.7 g/100 ml	i. eth.	*Digitalis lanata* & *D. purpurea*
18	Digoxin	$C_{41}H_{64}O_{14}$	265 d.	+13.3	0.001 g/100 ml	0.45 g/100 ml	i. chl., eth.	*Digitalis lanata*
19	Esculin	$C_{15}H_{16}O_9$	205 d.[1]	-38	0.175 g/100 ml	5 g/100 ml	s. h. chl., NaOH; sl. s. eth.	Leaves and bark of horse-chestnut tree
20	Gaultherin	$C_{19}H_{26}O_{12}$	179-180	-58	s.	s.	s. acet.; i. eth.	Wintergreen plant
21	Gitonin	$C_{50}H_{82}O_{23}$	272	-51	sl. s.	0.98 g/100 ml	s. acet.; i. eth.	*Digitalis purpurea*
22	Gitoxin	$C_{41}H_{64}O_{14}$	285	+3.5	sl. s.	....	s. eth.; i. acet. chl.	*Digitalis lanata* & *D. purpurea*
23	Gratiolin	$C_{43}H_{70}O_{15}$	235-237	.....	sl. s.	s.	s. chl.; sl. s. eth.	*Gratiola* sp.
24	Hesperidin	$C_{28}H_{34}O_{15}$	260-262	-76	v. sl. s.	sl. s. me. al.	s. NaOH; i. chl., eth.	Citrus plants
25	Indican	$C_{14}H_{17}O_6N$	176-178	-66	s.	s.	sl. s. chl., eth.	*Indigofera* spp.
26	Iridin	$C_{24}H_{26}O_{13}N$	208	.....	v. sl. s.	s. h.	i. chl., eth.	Rhizome of *Iris* spp.
27	Jalapin	$C_{34}H_{56}O_{16}$	131-150	.....	sl. s.	s.	s. chl., eth.	Scammony resin
28	Khellinin	$C_{19}H_{20}O_{10}$	175[1]	0	sl. s.	s. me. al.	i. eth.	Seeds of toothpick ammi
29	Ouabain	$C_{29}H_{44}O_{12}$	185 d.	-32.5	1.2 g/100 ml	1 g/100 ml	sl. s. chl., eth.	Seeds of *Strophanthus gratus*
30	Phlorizin	$C_{21}H_{24}O_{10}$	110[1]	-52	0.1 g/100 ml	25 g/100 ml	i. chl., eth.	Bark of fruit trees
31	Picrocrocin	$C_{16}H_{26}O_7$	154-156	-50	s.	s.	sl. s. chl., eth.	Crocus
32	Quercitrin	$C_{21}H_{20}O_{11}$	182-185[1]	.....	sl. s. h.; i. c.	s.	s. NaOH; i. eth.	Bark of quercitron
33	Rutin	$C_{27}H_{30}O_{16}$	215 d.	.....	sl. s. c.	sl. s.	i. chl., eth.	Buckwheat plant
34	Salicin	$C_{13}H_{18}O_7$	199-201	-67	4 g/100 ml	1 g/100 ml	i. chl., eth.	Bark of poplar, willow
35	Sarsasaponin	$C_{45}H_{74}O_{17}$	240	-66	s.	s. h.	sl. s. eth.	Radix of sarsaparilla

/1/ Hydrated salt.

benzene; c. = cold; chl. = chloroform; eth. = ether; h. = hot; i. = insoluble; me. al. = methyl alcohol; s. = soluble;

Uses	Aglycone	Melting Point °C	Specific Rotation $[\alpha]_D$	Sugar	Reference	
(I)	(J)	(K)	(L)	(M)	(N)	
In alcoholic beverages	.....	.....	.....	Glucose	6,30,50	1
Cathartic; amenorrhea	.....	.....	.....	Pentoses	17	2
No medical use	D-Mandelonitrile	.....	.....	Glucose	18,21,60	3
No medical use	Apigenin	350	.....	Glucose; apiose	26,62,70	4
No medical use	Hydroquinone	170	.....	Glucose	19,32,57	5
Cathartic	Aloe-emodin	224	.....	Glucose	9,48	6
Homeopathic therapy	Bryogenin	.....	.....	Glucose	1,36	7
Indicator; pigment in color photography, paints, bacteriology	Carmine red	.....	.....	.....	17	8
Preparation of vanillin	Coniferyl alcohol	73-74	.....	Glucose	39,40,55	9
Cardiotonic	Strophanthidin	235	+43.1	Rhamnose	13,34,43	10
No medical use	Methylethylacetic acid; tiglic acid	.....	.....	Glucose; rhodeose	33	11
Process of algae	Crocetin	285	.....	Gentiobiose	23,27,28	12
Cardiotonic	Strophanthidin	235	+43.1	Cymarose	61	13
Inflammation and vesication of skin; epispastic	7,8-Dihydroxycoumarin	253 d.	.....	Glucose	15,63	14
Cardiotonic	Diginigenin	115	-226	Giginose	44,51	15
Test for cholesterol and some other sterols	Digitogenin	250	-81	Glucose; galactose	16	16
Cardiotonic	Digitoxigenin	253	+19.1	Digitose	64	17
Cardiotonic	Digoxigenin	222	+27	Digitose	53	18
Sunburn protective	Esculetin	270 d.	.....	Glucose	37,58	19
Source of methyl salicylate	Methyl salicylate	-8.6	+1.2	Glucose; xylose	7,46	20
Similar to digitonin	Gitogenin	272	-61	Galactose; xylose	24,25	21
Cardiotonic	Gitoxigenin	235	+38.5	Digitoxose	10,54,65	22
No medical use	Gratiogenin	198	.....	Glucose	17	23
Decrease capillary fragility	3',5,7-Trihydroxy flavanone	390 d.	.....	Glucose	20,52,66	24
.....	Indoxyl	390	.....	Glucose	41,45,47	25
No medical use	Irigenin	186	.....	Glucose	3,4	26
No medical use	Jalapinolic	67-69	.....	Various	42	27
Smooth muscle relaxant	2-Hydroxymethyl-5-methoxy-furanochrome	155	.....	Glucose	56	28
Cardiotonic	Ouabagenin	255	+11.3	Rhamnose	22,44	29
Additive to lubricating oils; induce experimental glycosuria	Phloretin	271	.....	Glucose	8,38,67	30
Coloring; flavoring	Safranol	.....	.....	Glucose	28,31	31
Textile dye	Quercetin	314 d.	.....	Glucose	14,71	32
Decrease capillary fragility	Quercetin	313-314	.....	Glucose; rhamnose	2,11,68,69	33
Analgesic	Saligenin	87	.....	Glucose	12,29	34
Manufacture of pregnane compounds	Sarsapogenin	200	-75	Glucose; rhamnose	35,59	35

continued

99. GLYCOSIDES: CHARACTERISTICS,

	Glycoside	Chemical Formula	Melting Point °C	Specific Rotation $[\alpha]_D$	Solubility			Occurrence
					H_2O	Alcohol	Other	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
36	Solanine	$C_{45}H_{73}O_{15}N$	285 d.	-60	i.	s. h.	i. chl., eth.	*Solanum* spp.
37	Streptomycin hydrochloride	$C_{21}H_{39}O_{12}N_7 \cdot 3HCl$	....	-84	s.	v. sl. s.	i. chl., eth.	Cultures of *Streptomyces griseus*
38	Tannic acid	$C_{76}H_{52}O_{46}$	210-215 d.	.....	v. s.	sl. s.	v. sl. s. chl., eth.	Bark of oak, sumac

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100. FATTY ACIDS: PHYSICAL AND

Boiling Point (column F): d. = decomposes. **Solubility** (column K): a. = acid; acet. = acetone; ac. = acetic; hex. = hexane; h. = hot; me. = methyl; pent. = pentane, pet. = petroleum; pyr. = pyridine; s. = soluble; sl. = slightly;

	Acid		Chemical Formula	Molecular Weight	Melting Point °C	Boiling Point °C/mm[1]	Specific Gravity[2]
	Systematic Name	Common Name					
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Saturated Fatty Acids						
1	Methanoic	Formic	HCOOH	46.0	8.4	100.5	$1.220^{20°}$
2	Ethanoic	Acetic	CH_3COOH	60.1	16.7	118.2	$1.049^{20°}$
3	Propanoic	Propionic	C_2H_5COOH	74.1	-22.0	141.1	$0.992^{20°}$

/1/ 760 mm of mercury (atmospheric pressure), unless otherwise specified. /2/ At temperature indicated in in superscript. /4/ Milligrams KOH required to neutralize one gram of acid. /5/ Grams of iodine absorbed by 100

OCCURRENCE, AND USES

Uses	Aglycone	Melting Point °C	Specific Rotation $[\alpha]_D$	Sugar	Reference	
(I)	(J)	(K)	(L)	(M)	(N)	
No medical use	Solanidine	219	-29	Glucose; galactose; rhamnose	5,44	36
Tuberculosis; susceptible gram-negative bacteria; leprosy; granuloma inguinale	Streptidine	.....	.....	L-Streptose	49	37
Tanning; mordant in dyeing and printing; topically as astringent and styptic	Gallic acid	235 d.	.....	Glucose	17	38

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CHEMICAL CHARACTERISTICS

al. = alcohol; bz. = benzene; chl. = chloroform; cyc. = cyclohexane; eth. = ether; glac. = glacial; hept. = heptane; tol. = toluene; v. = very; w. = water.

Refractive Index[3] $n^{°C}_D$	Neutralization Value[4]	Iodine Value (Calculated)[5]	Solubility	Source	Reference	
(H)	(I)	(J)	(K)	(L)	(M)	
			Saturated Fatty Acids			
$1.3714^{20°}$	1,219	......	s.w.	Red ant	13,28,29	1
$1.3718^{20°}$	934.2	......	s.w.	Vinegar	15,28,29	2
$1.3874^{20°}$	757.3	......	s.al., chl., eth., w.	Milk and milk products	28,29	3

superscript, referred to water at 4°C. /3/ Refractive index (n) is given for the sodium D-line at temperature shown grams of acid.

continued

100. FATTY ACIDS: PHYSICAL AND

	Acid		Chemical Formula	Molecular Weight	Melting Point °C	Boiling Point °C/mm[1]	Specific Gravity[2]
	Systematic Name	Common Name					
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Saturated Fatty Acids						
4	Butanoic	Butyric	C_3H_7COOH	88.1	-7.9	163.5	0.9587^{20°
5	Pentanoic	Valeric	C_4H_9COOH	102.1	-34.5	187	0.942^{20°
6	Hexanoic	Caproic	$C_5H_{11}COOH$	116.2	-3.4	205.8	0.929^{20°
7	Heptanoic	Heptylic[6]	$C_6H_{13}COOH$	130.2	-10.5	223.0	0.92215^{20°
8	Octanoic	Caprylic	$C_7H_{15}COOH$	144.2	16.7	239.7	0.910^{20°
9	Nonanoic	Pelargonic	$C_8H_{17}COOH$	158.2	12.5	255.6	0.907^{20°
10	Decanoic	Capric	$C_9H_{19}COOH$	172.3	31.6	270	0.8858^{40°
11	Undecanoic[7]	Undecylic	$C_{10}H_{21}COOH$	186.3	29.3	284	0.9905^{25°
12	Dodecanoic	Lauric	$C_{11}H_{23}COOH$	200.3	44.2	225/100	0.8690^{50°
13	Tridecanoic	Tridecylic	$C_{12}H_{25}COOH$	214.3	41.5	236/100	0.8458^{80°
14	Tetradecanoic	Myristic	$C_{13}H_{27}COOH$	228.4	53.9	250/100	0.8622^{54°
15	Pentadecanoic	Pentadecylic	$C_{14}H_{29}COOH$	242.2	52.3	202.5/10	0.8423^{80°
16	Hexadecanoic	Palmitic	$C_{15}H_{31}COOH$	256.4	63.1	268/100	0.8487^{70°
17	Heptadecanoic	Margaric	$C_{16}H_{33}COOH$	270.4	61.3	220/10	0.853^{60°
18	Octadecanoic	Stearic	$C_{17}H_{35}COOH$	284.5	69.6	213/5	0.8390^{80°
19	Nonadecanoic	Nonadecylic	$C_{18}H_{37}COOH$	298.5	68.6	299/10	0.8771^{24°
20	Eicosanoic	Arachidic	$C_{19}H_{39}COOH$	312.5	76.5	204/1	0.8240^{100°
21	Docosanoic	Behenic	$C_{21}H_{43}COOH$	340.6	81.5	306/60	0.8221^{100°
22	Tetracosanoic	Lignoceric	$C_{23}H_{47}COOH$	368.6	86.0	272/10	0.8207^{100°
23	Hexacosanoic	Cerotic	$C_{25}H_{51}COOH$	396.7	88.5	....	0.8198^{100°
24	Octacosanoic	Montanic	$C_{27}H_{55}COOH$	424.7	90.9	....	0.8191^{100°
25	Triacontanoic	Melissic	$C_{29}H_{59}COOH$	452.8	93.6	....	....
26	Dotriacontanoic	Lacceroic	$C_{31}H_{63}COOH$	480.0	96.2	....	....
27	Tetratriacontanoic	Gheddic	$C_{33}H_{67}COOH$	508.9	98.4	....	....
28	Pentatriacontanoic	Ceroplastic	$C_{34}H_{69}COOH$	522.9	98.4	....	....
	Unsaturated Fatty Acids (Monoethenoic)						
29	*trans*-2-Butenoic	Crotonic	$C_4H_6O_2$	86.1	72	189.0	0.964^{80°
30	*cis*-2-Butenoic	Isocrotonic	$C_4H_6O_2$	86.1	15.5	169.3	1.0312^{15°
31	2-Hexenoic	Isohydrosorbic	$C_6H_{10}O_2$	114.1	32	217	0.965^{20°
32	4-Decenoic	Obtusilic	$C_{10}H_{18}O_2$	170.2	....	149/13	0.9197^{20°
33	9-Decenoic	Caproleic	$C_{10}H_{18}O_2$	170.2	....	142/4	0.9238^{15°
34	4-Dodecenoic	Linderic	$C_{12}H_{22}O_2$	198.3	1.0-1.3	171/13	0.9081^{20°
35	5-Dodecenoic	Denticetic	$C_{12}H_{22}O_2$	198.3	....	....	0.9130^{15°
36	9-Dodecenoic	Lauroleic	$C_{12}H_{22}O_2$	198.3	....	142/4	....
37	4-Tetradecenoic	Tsuzuic	$C_{14}H_{26}O_2$	226.4	18.0-18.5	185-188/13	0.9024^{20°
38	5-Tetradecenoic	Physcteric	$C_{14}H_{26}O_2$	226.4	....	190-195/15	0.9046^{20°
39	9-Tetradecenoic	Myristoleic	$C_{14}H_{26}O_2$	226.4	-4	....	0.9018^{20°
40	9-Hexadecenoic	Palmitoleic	$C_{16}H_{30}O_2$	254.4	-0.5 to +0.5	131/0.06	....
41	6-Octadecenoic	Petroselinic	$C_{18}H_{34}O_2$	282.5	32-33	237.5/18	0.8824^{35°
42	*cis*-9-Octadecenoic	Oleic	$C_{18}H_{34}O_2$	282.5	13.4(α), 16.3(β)	234/15	0.8905^{20°
43	*trans*-9-Octadecenoic	Elaidic	$C_{18}H_{34}O_2$	282.5	44.5	288/100	0.851^{79°
44	*trans*-11-Octadecenoic	Vaccenic	$C_{18}H_{34}O_2$	282.5	44	....	0.8563^{70°
45	9-Eicosenoic	Gadoleic	$C_{20}H_{38}O_2$	310.5	24-24.5	220/6	0.8882^{25°
46	11-Eicosenoic	Gondoic	$C_{20}H_{38}O_2$	310.5	23.5-24	267/15	....
47	11-Docosenoic	Cetoleic	$C_{22}H_{42}O_2$	338.6	32.5-33	....	....
48	13-Docosenoic	Erucic	$C_{22}H_{42}O_2$	338.6	34.7	242/5	0.85321^{70°
49	15-Tetracosenoic	Nervonic[8]	$C_{24}H_{46}O_2$	366.6	42.5-43.0	....	....
50	17-Hexacosenoic	Ximenic	$C_{26}H_{50}O_2$	394.7	45-45.5	....	....
51	21-Triacontenoic	Lumequeic	$C_{30}H_{58}O_2$	450.8	....	....	....
	Unsaturated Fatty Acids (Dienoic)						
52	2,4-Pentadienoic	β-Vinylacrylic	$C_5H_6O_2$	98.1	80	110 α	....
53	2,4-Hexadienoic	Sorbic	$C_6H_8O_2$	112.1	134.5	228 α.	....
54	2,4-Decadienoic	Stillingic	$C_{10}H_{16}O_2$	168.2	....	....	....
55	2,4-Dodecadienoic	....	$C_{12}H_{20}O_2$	196.3	....	....	....
56	9,12-Hexadecadienoic	....	$C_{16}H_{28}O_2$	252.4	....	....	....
57	*cis*-9, *cis*-12-Octadecadienoic	α-Linoleic	$C_{18}H_{32}O_2$	280.5	-5.2 to -5.0	202/1.4	0.9038^{18°

/1/ 760 mm of mercury (atmospheric pressure), unless otherwise specified. /2/ At temperature indicated in superscript. /4/ Milligrams KOH required to neutralize one gram of acid. /5/ Grams of iodine absorbed by 100

CHEMICAL CHARACTERISTICS

Refractive Index[3] $n_{D}^{^\circ C}$	Neutralization Value[4]	Iodine Value (Calculated)[5]	Solubility	Source	Reference	
(H)	(I)	(J)	(K)	(L)	(M)	
Saturated Fatty Acids						
1.33906^{20°	636.8	......	s.al., eth., w.	Butterfat	13,29,36	4
1.4086^{20°	549.3	......	s.al., eth.; sl.s.w.	Essential oils	29,36	5
1.41635^{20°	483.0	......	s.al., eth.; sl.s.w.	Butterfat, palm oils	29,36	6
1.4230^{20°	431.0	......	s.al., eth.; v.sl.s.w.	Violet-leaf oil	29,36	7
1.4285^{20°	389.1	......	s.al., bz., eth.; v.sl.s.w.	Butterfat, palm-kernel oils	13,29,36	8
1.4322^{20°	354.6	......	s.al., chl., eth.; v.sl.s.w.	Butterfat, hair fat	29,36	9
1.42855^{40°	325.7	......	s.al., eth., pet.eth.; v.sl.s.w.	Butterfat, palm-kernel oils	13,29,36	10
1.4202^{70°	301.2	......	s.al., chl., eth., pet.eth.	Hair fat (human)	29,36	11
1.4261^{60°	280.1	......	s.acet., al., eth., pet.eth.	Lauraceae oils	13,29,36	12
1.4286^{60°	261.8	......	s.acet., al., eth., pet.eth.	Hair fat (human)	14,29,31,36	13
1.4273^{70°	245.7	......	s.acet., al., eth., pet.eth.	Myristicaceae fats	13,29,36	14
1.4292^{70°	231.5	......	s.acet., al., eth., pet.eth.	Mutton, hair, & milk fats	29,36	15
1.4309^{70°	218.8	......	s.acet., h.al., eth., pet.eth.	Palm-pulp oils	29,36	16
1.4324^{70°	207.5	......	s.acet., h.al., eth., pet.eth.	Hair & mutton fats	29,36	17
1.4337^{70°	197.2	......	s.acet., h.al., eth., pet.eth.	Animal fats generally	13,29,36	18
1.4512^{25°	188.0	......	s.acet., h.al., eth., pet.eth.	Ox fat	29	19
1.4250^{100°	179.5	......	s.bz., chl., eth., pet.eth.	Peanut oil, rambutan fat	13,29, 36	20
1.4270^{100°	164.7	......	sl.s.al., eth.	Moringa (ben) oils	13,29,36	21
1.4287^{100°	152.2	......	s.ac.a., bz., CS_2, eth.	Beech-tar paraffin	28,29,36,39	22
1.4301^{100°	141.4	......	s.h.acet., h.chl., h.me.al.	Insect, wool, & leaf waxes	13,29,36	23
1.4313^{100°	132.1	......	s.h.ac.a., h.bz., h.me.al.	Insect, leaf, & montan waxes	13,29,36	24
1.4323^{100°	123.9	......	s.chl., CS_2, h.me.al.	Insect & mineral waxes	13,29,36	25
....	116.7	......	s.h.acet., h.bz., chl.	Stick-lac wax	13,17,29,36	26
....	110.2	......	s.h.acet., h.bz., chl.	Ghedda wax	13,29,32,36	27
....	107.3	......	s.h.acet., h.bz., chl.	*Ceroplastes rubens*	13,29,32,36	28
Unsaturated Fatty Acids (Monoethenoic)						
1.4228^{80°	651.7	294.9	s.acet., al., tol., w.	Croton oil	29	29
1.4457^{20°	651.7	294.9	s.al., pet.eth., w.	Croton oil	29	30
1.4460^{40°	491.5	222.5	s.CS_2, eth.	Japanese mint oils	29,36	31
1.4497^{20°	329.6	149.1	s.bz., eth.	*Lindera* seed oils	2,13,29,36	32
1.4507^{15°	329.6	149.1	s.al., eth.	Milk fats, whale oil	13,29,36,37	33
1.4529^{20°	282.9	128.0	s.bz., chl., eth.	*Lindera* seed oils	13,29,36	34
1.4535^{15°	282.9	128.0	s.bz., chl., eth.	Herring & whale oils	13,29,36,39	35
....	282.9	128.0	s.bz., chl., eth.	Milk fats, cochineal wax	13,29,36	36
1.4557^{20°	247.9	112.2	s.bz., pet.eth.	*Lindera* seed oils	2,13,29,36	37
1.4552^{20°	247.9	112.2	s.bz., eth., pet.eth.	Whale & fish oils	13,29,36,39	38
1.4519^{20°	247.9	112.2	s.bz., eth., pet.eth.	Milk fats, whale oil	2,13,29,36	39
....	220.5	99.8	s.bz., eth., pet.eth.	Marine oils, milk fats	2,13,18,29	40
1.4533^{40°	198.6	89.9	s.al., eth., pet.eth.	Parsley-seed oil	13,21,22,29, 36	41
1.45823^{20°	198.6	89.9	s.acet., eth., me.al.	Olive oil, pork fat	13,29,36	42
1.4468^{50°	198.6	89.9	s.al., chl., eth., pet.eth.	Beef & sheep fats	29	43
1.4406^{70°	198.6	89.9	s.acet., me.al.	Milk, beef, & sheep fats	13,29,36	44
1.4597^{25°	180.7	81.8	s.acet., me.al., pet.eth.	Sperm & fish-liver oils	13,16,21,29	45
....	180.7	81.8	s.al., me.al.	Crucifer, jojoba, & fish oils	13,16,29	46
....	165.7	75.0	s.al.	Marine oils	13,21,29,39	47
1.4444^{70°	165.7	75.0	v.s.eth., me.al.	Crucifer oils	13,29,30,36	48
....	153.0	69.2	s.acet., al., eth.	Shark-liver oil, cerebrosides	13,21,29,36	49
....	142.2	64.3	s.bz., chl., eth., pet.eth.	*Ximenia* oils	13,29	50
....	124.5	56.3	s.bz., chl., eth., pet.eth.	*Ximenia* oils	13,29	51
Unsaturated Fatty Acids (Dienoic)						
....	572.0	517.5	v.s.al., eth.; s.h.w.	Synthetic	29,36	52
....	500.4	452.7	s.al., eth.; sl.s.w.	Mountain-ash berry	29,36	53
....	333.5	301.7	s.acet., eth., hex.	*Stillingia* oils	29	54
....	285.8	258.6	s.acet., eth., pet.eth.	*Sebastiania fruticosa* seed oil	29	55
....	222.3	201.1	s.acet., eth., pet.eth.	*Asclepias syriaca* seed oil	7	56
1.4699^{20°	200.1	181.0	s.acet., al., eth., pet.eth.	Numerous seed oils	13,29,36	57

superscript, referred to water at 4°C. /3/ Refractive index (n) is given for the sodium D-line at temperature shown grams of acid. /6/ Also called enanthic acid. /7/ Also called hendecanoic acid. /8/ Also called selacholeic acid.

continued

	Acid: Systematic Name	Acid: Common Name	Chemical Formula	Molecular Weight	Melting Point °C	Boiling Point °C/mm[1]	Specific Gravity[2]
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Unsaturated Fatty Acids (Dienoic)						
58	*trans*-9, *trans*-12-Octadecadienoic	Linolelaidic	$C_{18}H_{32}O_2$	280.5	28-29	...	...
59	*trans*-10, *trans*-12-Octadecadienoic	...	$C_{18}H_{32}O_2$	280.5	55.5-56	...	...
60	11,14-Eicosadienoic	...	$C_{20}H_{36}O_2$	308.4	...	...	...
61	13,16-Docosadienoic	...	$C_{22}H_{40}O_2$	336.6	...	...	...
62	17,20-Hexacosadienoic		$C_{26}H_{48}O_2$	392.7	61	...	...
	Unsaturated Fatty Acids (Trienoic)						
63	6,10,14-Hexadecatrienoic	Hiragonic	$C_{16}H_{26}O_2$	250.4	...	180-190/15	0.9296^{20°
64	7,10,13-Hexadecatrienoic	...	$C_{16}H_{26}O_2$	250.4	...	...	...
65	*cis*-6, *cis*-9, *cis*-12-Octadecatrienoic	γ-Linolenic	$C_{18}H_{30}O_2$	278.4	...	...	...
66	*trans*-8, *trans*-10, *cis*-12-Octadecatrienoic	α-Calendic	$C_{18}H_{30}O_2$	278.4	40-40.5	...	...
67	*trans*-8, *trans*-10, *trans*-12-Octadecatrienoic	β-Calendic	$C_{18}H_{30}O_2$	278.4	77-78	...	...
68	*cis*-8, *trans*-10, *cis*-12-Octadecatrienoic	...	$C_{18}H_{30}O_2$	278.4	...	...	...
69	*cis*-9, *cis*-12, *cis*-15-Octadecatrienoic	α-Linolenic	$C_{18}H_{30}O_2$	278.4	-10 to -11.3	157/0.001	0.914^{20°
70	*trans*-9, *trans*-12, *trans*-15-Octadecatrienoic	Linolenelaidic	$C_{18}H_{30}O_2$	278.4	29-30	...	...
71	*cis*-9, *trans*-11, *trans*-13-Octadecatrienoic	α-Eleostearic	$C_{18}H_{30}O_2$	278.4	48-49	235/15	...
72	*trans*-9, *trans*-11, *trans*-13-Octadecatrienoic	β-Eleostearic	$C_{18}H_{30}O_2$	278.4	71.5	...	...
73	*cis*-9, *trans*-11, *cis*-13-Octadecatrienoic	Punicic	$C_{18}H_{30}O_2$	278.4	43.5-44	...	0.9027^{50°
74	*trans*-9, *trans*-11, *trans*-13-Octadecatrienoic	...	$C_{18}H_{30}O_2$	278.4	...	...	...
75	5,8,11-Eicosatrienoic	...	$C_{20}H_{34}O_2$	306.5	...	...	...
76	8,11,14-Eicosatrienoic	...	$C_{20}H_{34}O_2$	306.5	...	...	...
	Unsaturated Fatty Acids (Tetraenoic)						
77	4,8,11,14-Hexadecatetraenoic	...	$C_{16}H_{24}O_2$	248.4	...	...	...
78	6,9,12,15-Hexadecatetraenoic	...	$C_{16}H_{24}O_2$	248.4	...	...	...
79	4,8,12,15-Octadecatetraenoic	Moroctic	$C_{18}H_{28}O_2$	276.4	...	208-213/15	0.9297^{20°
80	6,9,12,15-Octadecatetraenoic	...	$C_{18}H_{28}O_2$	276.4	-57.4 to -56.6	...	...
81	9,11,13,15-Octadecatetraenoic	α-Parinaric	$C_{18}H_{28}O_2$	276.4	85-86	...	...
82	9,11,13,15-Octadecatetraenoic	β-Parinaric	$C_{18}H_{28}O_2$	276.4	95-96	...	...
83	9,12,15,18-Octadecatetraenoic	...	$C_{18}H_{28}O_2$	276.4	...	...	...
84	4,8,12,16-Eicosatetraenoic	...	$C_{20}H_{32}O_2$	304.5	...	217-220/10	0.9263^{20°
85	5,8,11,14-Eicosatetraenoic	Arachidonic	$C_{20}H_{32}O_2$	304.5	-49.5	163/1	0.9082^{20°
86	6,10,14,18-Eicosatetraenoic ?	...	$C_{20}H_{32}O_2$	304.5	...	...	0.9263^{20°
87	4,7,10,13-Docosatetraenoic	...	$C_{22}H_{36}O_2$	332.5	...	...	...
88	7,10,13,16-Docosatetraenoic	...	$C_{22}H_{36}O_2$	332.5	...	...	...
89	8,12,16,19-Docosatetraenoic	...	$C_{22}H_{36}O_2$	332.5	...	...	...
	Unsaturated Fatty Acids (Penta- and Hexa-enoic)						
90	4,8,12,15,18-Eicosapentaenoic	Timnodonic ?	$C_{20}H_{30}O_2$	302.5	...	...	0.9399^{15°
	5,8,11,14,17-Eicosapentaenoic	...	$C_{20}H_{30}O_2$	302.5	-54.4 to -53.8	...	...
92	4,7,10,13,16-Docosapentaenoic	...	$C_{22}H_{34}O_2$	330.5	...	...	...
93	4,8,12,15,19-Docosapentaenoic	Clupanodonic	$C_{22}H_{34}O_2$	330.5	...	207-212/2	0.9356^{20°
94	7,10,13,16,19-Docosapentaenoic	...	$C_{22}H_{34}O_2$	330.5	...	...	...
95	4,7,10,13,16,19-Docosahexaenoic	...	$C_{22}H_{32}O_2$	328.5	-44.5 to -44.1	...	...
96	4,8,12,15,18,21-Tetracosahexaenoic	Nisinic	$C_{24}H_{36}O_2$	356.6	...	...	0.9452^{20°

/1/ 760 mm of mercury (atmospheric pressure), unless otherwise specified. /2/ At temperature indicated in in superscript. /4/ Milligrams KOH required to neutralize one gram of acid. /5/ Grams of iodine absorbed by 100

CHEMICAL CHARACTERISTICS

Refractive Index[3] $n_{D}^{\circ C}$	Neutral-ization Value[4]	Iodine Value (Calcu-lated)[5]	Solubility	Source	Reference	
(H)	(I)	(J)	(K)	(L)	(M)	
			Unsaturated Fatty Acids (Dienoic)			
....	200.1	181.0	s.al., eth., me.al., pet.eth.	Isomerized α-acid	29,36	58
....	200.1	181.0	s.acet., cyc., eth.	*Chilopsis linearis* seed oil	23	59
....	181.9	164.5	s.acet., eth., pet.eth.	Shark-liver oil	29	60
....	166.7	150.8	s.acet., eth.	*Brassica* seed oils	29	61
....	142.9	129.3	s.eth., pet.eth.	*Spheciospongia* sponge	29	62
			Unsaturated Fatty Acids (Trienoic)			
1.4850^{50C}	224.1	304.1	s.al., eth.	Sardine oil	13,29,36,38	63
....	224.1	304.1	s.al., eth.	*Brassica napus* leaves	29	64
....	201.5	273.5	s.acet., eth., me.al.	*Oenothera biennis* seed oil	29,36	65
....	201.5	273.5	s.acet., pent.	*Calendula officinalis* seed oil	8,29,36	66
....	201.5	273.5	s.me.al., pet.eth.	Elaidinized α-acid	8	67
....	201.5	273.5	v.s.acet., al., pent., pet.eth.	*Jacaranda* oils	10,29	68
$1.4678^{50°}$	201.5	273.5	s.acet., al., eth., pet.eth.	Linseed, perilla, & hemp oils	13,29,36	69
....	201.5	273.5	s.me.al., pet.eth.	Elaidinized α-acid	29,36	70
$1.5112^{50°}$	201.5	273.5	s.al., cyc., eth., pet.eth.	Tung, po-yak, & neou oils	13,28,29,36	71
$1.5002^{75°}$	201.5	273.5	s.al., eth., me.al., pet.eth.	Elaidinized α-acid	13,29,36	72
$1.5114^{50°}$	201.5	273.5	s.al., pent., pet.eth.	*Trichosanthes* oils	13,29,36	73
....	201.5	273.5	s.acet., al., CS_2, pent.	*Catalpa ovata* seed oil	9,29	74
....	183.1	248.3	s.CS_2, hept., me.al.	Bovine-liver phosphatides	29	75
....	183.1	248.3	s.CS_2, hept., me.al.	Bovine-liver phosphatides	29	76
			Unsaturated Fatty Acids (Tetraenoic)			
....	225.9	408.8	s.acet., al., eth., pet.eth.	Sardine oil	29	77
$1.4870^{29°}$	225.9	408.8	s.acet., al., CS_2, eth., pent.	Pilchard & herring oils	29	78
$1.4911^{20°}$	203.0	367.3	s.acet., al., eth., pet.eth.	Sardine oil	13,29,36,38	79
$1.4888^{16°}$	203.0	367.3	s.CS_2, me.al.	Pilchard & herring oils	29	80
....	203.0	367.3	s.acet., al., eth., pet.eth.	*Parinarium & Impatiens* seed oils	13,29,36	81
....	203.0	367.3	s.eth., pet.eth.	Elaidinized α-acid	13,29,36	82
....	203.0	367.3	s.CS_2, me.al.	Herring oil	29	83
$1.4915^{20°}$	184.3	333.4	s.acet., eth.	Fish & whale oils	13,29,36	84
$1.4824^{20°}$	184.3	333.4	s.acet., eth., me.al., pet.eth.	Brain, liver, egg, & glandular lipids	13,29,36	85
$1.4935^{20°}$	184.3	333.4	s.acet., me.al., pet.eth.	Sardine oil	29	86
....	168.7	305.4	s.acet., me.al., pet.eth.	Brain phosphatides	24,29	87
....	168.7	305.4	s.CS_2, hept., me.al.	Brain & bovine-liver phosphatides	24,29	88
....	168.7	305.4	s.acet., me.al., pet.eth.	Shark-liver oil	1,29	89
			Unsaturated Fatty Acids (Penta- and Hexa-enoic)			
$1.5109^{15°}$	185.5	419.6	s.bz., chl., eth., pet.eth.	Sardine & bonito oils	13,29,36	90
$1.4977^{23°}$	185.5	419.6	s.hept., me.al.	Bovine-liver lipids, pilchard oil	25	91
....	169.8	384.0	s.chl., hept., me.al.	Brain lipids	24,29	92
$1.5014^{20°}$	169.8	384.0	s.acet., eth., pet.eth.	Marine oils	13,29,36	93
....	169.8	384.0	s.bz., chl., me.al., pet.eth.	Bovine-liver lipids, herring oil	26,29	94
$1.5017^{26°}$	170.8	463.6	s.bz., chl., me.al., pet.eth.	Bovine-liver & hog-brain lipids, pilchard oil	19,24,29	95
$1.5122^{20°}$	157.4	427.1	s.bz., chl., eth., pet.eth.	Whale & fish-liver oils	13,29,36	96

superscript, referred to water at 4°C. /3/ Refractive index *(n)* is given for the sodium D-line at temperature shown grams of acid.

continued

	Acid: Systematic Name	Acid: Common Name	Chemical Formula	Molecular Weight	Melting Point °C	Boiling Point °C/mm[1]	Specific Gravity[3]
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Hydroxyalkanoic Acids						
97	2-Hydroxydodecanoic	2-Hydroxylauric	$C_{12}H_{24}O_3$	216.3	73-74	...	...
98	12-Hydroxydodecanoic	Sabinic	$C_{12}H_{24}O_3$	216.3	84	...	...
99	2-Hydroxytetradecanoic	2-Hydroxymyristic	$C_{14}H_{28}O_3$	244.4	81.5-82	...	...
100	11-Hydroxypentadecanoic	Convolvulinolic	$C_{15}H_{30}O_3$	258.4	63.5-64	...	...
101	2-Hydroxyhexadecanoic	2-Hydroxypalmitic	$C_{16}H_{32}O_3$	272.4	86-87	...	...
102	11-Hydroxyhexadecanoic	Jalapinolic	$C_{16}H_{32}O_3$	272.4	68-69	...	...
103	16-Hydroxyhexadecanoic	Juniperic	$C_{16}H_{32}O_3$	272.4	95	...	...
104	2-Hydroxyoctadecanoic	2-Hydroxystearic	$C_{18}H_{36}O_3$	300.5	91	...	...
105	23-Hydroxydocosanoic	Phellonic	$C_{22}H_{44}O_3$	356.6	95-96	...	...
106	2-Hydroxytetracosanoic	Cerebronic	$C_{24}H_{48}O_3$	384.6	99.5-100.5	...	...
107	3,11-Dihydroxytetradecanoic	Ipurolic	$C_{14}H_{28}O_4$	260.4	100-101	...	...
108	2,15-Dihydroxypentadecanoic	Dihydroxypentadecylic	$C_{15}H_{30}O_4$	274.4	102-103	...	...
109	15,16-Dihydroxyhexadecanoic	Ustilic A	$C_{16}H_{32}O_4$	288.4	112-113	...	...
110	9,10-Dihydroxyoctadecanoic	9,10-Dihydroxystearic	$C_{18}H_{36}O_4$	316.5	141[9]	...	...
111	9,10-Dihydroxyoctadecanoic	9,10-Dihydroxystearic	$C_{18}H_{36}O_4$	316.5	90[10]	...	...
112	11,12-Dihydroxyeicosanoic	11,12-Dihydroxyarachidic	$C_{20}H_{40}O_4$	344.5	130[9]	...	...
113	2,15,16-Trihydroxyhexadecanoic	Ustilic	$C_{16}H_{32}O_5$	304.4	140	...	...
114	9,10,16-Trihydroxyhexadecanoic	Aleuritic	$C_{16}H_{32}O_5$	304.4	100	...	...
	Keto, Epoxy, and Cyclo Fatty Acids						
115	4-Ketopentanoic	Levulinic	$C_5H_8O_3$	116.1	37.2	154/15	$1.1395^{20°}$
116	6-Ketooctadecanoic	Lactarinic	$C_{18}H_{34}O_3$	298.5	87	...	...
117	4-Keto-9,11,13-octadecatrienoic	α-Licanic	$C_{18}H_{28}O_3$	292.4	74-75	...	...
118	4-Keto-*trans*-9, *trans*-11,-*trans*-13-octadecatrienoic	β-Licanic	$C_{18}H_{28}O_3$	292.4	99.5	...	...
119	*cis*-12,13-Epoxy-*cis*-9-octadecenoic	Vernolic	$C_{18}H_{32}O_3$	296.5	31-32	...	...
120	*cis*-9,10-Epoxyoctadecanoic	Epoxystearic	$C_{18}H_{34}O_3$	298.5	57.5-58	...	...
121	ω-(2-*n*-Octylcycloprop-1-enyl)-octanoic	Sterculic	$C_{19}H_{34}O_2$	294.5	18	...	...
122	ω-(2-*n*-Octylcyclopropyl)-octanoic	Lactobacillic	$C_{19}H_{36}O_2$	296.5	28-29	...	...
123	13-(2-Cyclopentenyl)-tridecanoic	Chaulmoogric	$C_{18}H_{32}O_2$	280.2	68.5	247.5/20	...
124	11-(2-Cyclopentenyl)-hendecanoic	Hydnocarpic	$C_{16}H_{28}O_2$	252.2	60.5	...	...
125	9-(2-Cyclopentenyl)-nonanoic	Alepric	$C_{14}H_{24}O_2$	224.2	48.0	...	...
126	7-(2-Cyclopentenyl)-heptanoic	Aleprylic	$C_{12}H_{20}O_2$	196.2	32.0	...	...
127	5-(2-Cyclopentenyl)-pentanoic	Aleprestic	$C_{10}H_{16}O_2$	168.1	Liquid	...	...
128	2-Cyclopentenyl-1-oic	Aleprolic	$C_6H_8O_2$	112.1	Liquid	...	...
129	13-(2-Cyclopentenyl)-6-tridecenoic	Gorlic	$C_{18}H_{30}O_2$	278.2	6.0	232.5	$0.9436^{25°}$
	Hydroxy Unsaturated Acids						
130	16-Hydroxy-7-hexadecenoic	Ambrettolic	$C_{16}H_{30}O_3$	270.5	25	...	...
131	9-Hydroxy-12-octadecenoic	...	$C_{18}H_{34}O_3$	298.5	...	...	...
132	*d*-12-Hydroxy-*cis*-9-octadecenoic	Ricinoleic	$C_{18}H_{34}O_3$	298.5	5, 7.7, & 16	225/10	$0.940^{27.4°}$
133	*d*-12-Hydroxy-*trans*-9-octadecenoic	Ricinelaidic	$C_{18}H_{34}O_3$	298.5	52-53	...	...
134	2-Hydroxy-15-tetracosenoic	Hydroxynervonic	$C_{24}H_{46}O_3$	382.6	65	...	...
135	9-Hydroxy-10,12-octadecadienoic	...	$C_{18}H_{32}O_3$	296.5	...	...	...

/1/ 760 mm of mercury (atmospheric pressure), unless otherwise specified. /3/ At temperature indicated in in superscript. /4/ Milligrams KOH required to neutralize one gram of acid. /5/ Grams of iodine absorbed by 100

CHEMICAL CHARACTERISTICS

Refractive Index[3] $n_D^{°C}$	Neutralization Value[4]	Iodine Value (Calculated)[5]	Solubility	Source	Reference	
(H)	(I)	(J)	(K)	(L)	(M)	
Hydroxyalkanoic Acids						
....	259.4	......	s.al., me.al.	Wool wax	29	97
....	259.4	......	s.al., h.bz.	Juniper wax	3,13,29	98
....	229.1	......	s.al., chl., eth.	Beeswax, wool wax	29	99
....	217.1	......	s.al., chl., eth.	Convolvulin resin	13,29,34	100
....	206.0	......	s.al., me.al.	Wool wax	29,40	101
....	206.0	......	s.al., eth.	Jalap-root resin	13,29,33	102
....	206.0	......	s.al., bz., eth.	Conifer waxes	13,21,29,36	103
....	186.7	......	s.al., me.al.	Wool wax	29,40	104
....	157.3	......	s.acet., chl., eth., glac.ac.a, pyr.	Cork	5,13,29,36	105
....	145.9	......	s.acet., h.al., eth., pyr.	Cerebrosides	13,29,36	106
....	215.5	......	s.chl., eth.	*Ipomoea purpurea*	13,29,33	107
....	204.5	......	s.me.al.	Ustilic acid B	29	108
....	194.5	......	s.me.al.	Fermentation of *Ustilago zeae*	29	109
....	177.3	......	s.h.al.; sl.s.eth.	Castor oil	13,29	110
....	177.3	......	s.al., eth., h.w.	Soils and straw	29	111
....	162.9	......	s.acet., eth.	Rabbit's-ear & mustard-seed oils	13,29	112
....	184.3	......	s.me.al.	Fermentation of *Ustilago zeae*	29	113
....	184.3	......	s.me.al.	Shellac wax	29	114
Keto, Epoxy, and Cyclo Fatty Acids						
$1.442^{15.8°}$	483.2	......	v.s.al., eth., w.	Hexoses + HCl	29	115
....	188.0	......	s.h.al., chl., eth.	*Lactarius* mushrooms	13,21,29,36	116
....	191.9	260.4	s.h.pet.eth.	Oiticica oil	4,15,29,36	117
....	191.9	260.4	s.h.pet.eth.	Elaidinized α-acid	4,15,29,36	118
....	189.3	85.6	s.acet., al., hex.	*Vernonia anthelmintica* seed oil	27,29	119
....	188.0	......	s.acet., al., hex.	*Tragopogon porrifolius* seed oil	6	120
....	190.5	86.2	s.eth.	*Sterculia foetida* seed oil	29	121
....	189.2	......	s.acet., eth., pet.eth.	*Lactobacillus plantarum* lipids	29	122
....	200.1	90.5	s.acet., chl., eth.	*Hydnocarpus* seed oils	12,13,21,29, 36	123
....	222.3	100.6	s.al., chl., pet.eth.	*Hydnocarpus* seed oils	21,29,36	124
....	250.1	113.1	s.al., eth., pet.eth.	*Hydnocarpus* seed oils	29	125
....	285.8	129.3	s.acet., eth., pet.eth.	*Hydnocarpus* seed oils	29	126
....	333.5	150.8	s.acet., eth., pet.eth.	*Hydnocarpus* seed oils	29	127
....	500.4	226.4	s.acet., eth., pet.eth.	*Hydnocarpus* seed oils	29	128
$1.4782^{25°}$	201.5	182.5	s.h.al.	Gorli oil	11,13,29,36	129
Hydroxy Unsaturated Acids						
....	207.5	93.9	s.al., eth.	Musk-seed oil	29,36	130
....	188.0	85.0	s.acet., al., eth.	*Strophanthus* seed oils	29	131
$1.4716^{20°}$	188.0	85.0	s.acet., al., eth.	Castor & ergot oils	13,29,36	132
....	188.0	85.0	s.acet., al., eth.	Elaidinized ricinoleic acid	13,29,36	133
....	146.6	66.3	s.acet., al., chl., eth., pyr.; sl.s. pet.eth.	Cerebrosides	13,29,36	134
....	189.2	171.2	s.acet., al., pent.	*Tragopogon porrifolius* seed oil	8	135

superscript, referred to water at 4°C. /3/ Refractive index (*n*) is given for the sodium D-line at temperature shown grams of acid. /9/ *Erythro*. /10/ *Threo*.

continued

	Acid: Systematic Name	Acid: Common Name	Chemical Formula	Molecular Weight	Melting Point °C	Boiling Point °C/mm[1]	Specific Gravity[2]
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Hydroxy Unsaturated Acids						
136	13-Hydroxy-9,11-octadecadienoic	....	$C_{18}H_{32}O_3$	296.5	....	....	....
137	18-Hydroxy-*cis*-9, *trans*-11,-*trans*-13-octadecatrienoic	α-Kamlolenic	$C_{18}H_{30}O_3$	294.4	77-78	....	....
138	18-Hydroxy-*trans*-9, *trans*-11, *trans*-13-octadecatrienoic	β-Kamlolenic	$C_{18}H_{30}O_3$	294.4	88-89	....	....
	Branched-Chain Fatty Acids						
139	3-Methylbutanoic	Isovaleric	$C_5H_{10}O_2$	102.1	-37.6	176.7	$0.937^{15°}$
140	*d*-6-Methyloctanoic	....	$C_9H_{18}O_2$	158.2	....	....	....
141	8-Methyldecanoic	....	$C_{11}H_{22}O_2$	186.3	-18.5	....	....
142	10-Methylhendecanoic	Isolauric	$C_{12}H_{24}O_2$	200.3	41.2	....	....
143	*d*-10-Methyldodecanoic	....	$C_{13}H_{26}O_2$	214.3	6.2-6.5	....	....
144	11-Methyldodecanoic	Isoundecylic	$C_{13}H_{26}O_2$	214.3	39.4-40	....	....
145	12-Methyltridecanoic	Isomyristic	$C_{14}H_{28}O_2$	228.4	53.6	....	....
146	*d*-12-Methyltetradecanoic	....	$C_{15}H_{30}O_2$	242.4	25.8	....	....
147	13-Methyltetradecanoic	Isopentadecylic	$C_{15}H_{30}O_2$	242.4	52.2	....	....
148	14-Methylpentadecanoic	Isopalmitic	$C_{16}H_{32}O_2$	256.4	62.4	....	....
149	*d*-14-Methylhexadecanoic	....	$C_{17}H_{34}O_2$	270.4	38.0	....	....
150	15-Methylhexadecanoic	....	$C_{17}H_{34}O_2$	270.4	60.5	....	....
151	10-Methylheptadecanoic	....	$C_{18}H_{36}O_2$	284.5	33.5	....	....
152	16-Methylheptadecanoic	Isostearic	$C_{18}H_{36}O_2$	284.5	69.5	....	....
153	*l*-D-10-Methyloctadecanoic	Tuberculostearic	$C_{19}H_{38}O_2$	298.5	13.2	175-178/0.7	$0.887^{25°}$
154	*d*-16-Methyloctadecanoic	....	$C_{19}H_{38}O_2$	298.5	49.9-50.7	....	....
155	18-Methylnonadecanoic	Isoarachidic	$C_{20}H_{40}O_2$	312.5	75.3	....	....
156	*d*-18-Methyleicosanoic	....	$C_{21}H_{42}O_2$	326.6	55.6	....	....
157	20-Methylheneicosanoic	Isobehenic	$C_{22}H_{44}O_2$	340.6	79.5	....	....
158	*d*-20-Methyldocosanoic	....	$C_{23}H_{46}O_2$	354.6	62.1	....	....
159	22-Methyltricosanoic	Isolignoceric	$C_{24}H_{48}O_2$	368.6	83.1	....	....
160	*d*-22-Methyltetracosanoic	....	$C_{25}H_{50}O_2$	382.7	67.8	....	....
161	24-Methylpentacosanoic	Isocerotic	$C_{26}H_{52}O_2$	396.7	86.9	....	....
162	*d*-24-Methylhexacosanoic	....	$C_{27}H_{54}O_2$	410.7	72.9	....	....
163	26-Methylheptacosanoic	Isomontanic	$C_{28}H_{56}O_2$	424.7	89.3	....	....
164	*d*-28-Methyltriacontanoic	....	$C_{31}H_{62}O_2$	466.8	80.7	....	....
165	2,4,6-(D)-Trimethyloctacosanoic	Mycoceranic(mycocerosic)	$C_{31}H_{62}O_2$	466.8	27-28	....	....
166	2-Methyl-*cis*-2-butenoic	Angelic	$C_5H_8O_2$	100.1	45	185	$0.983^{47°}$
167	2-Methyl-*trans*-2-butenoic	Tiglic	$C_5H_8O_2$	100.1	65.5	198.5	....
168	4-Methyl-3-pentenoic	Pyroterebic	$C_6H_{10}O_2$	114.1	....	207	....
169	*d*-2,4(L),6(L)-Trimethyl-*trans*-2-tetracosenoic	C_{27}-Phthienoic (mycolipenic)	$C_{27}H_{52}O_2$	408.7	39.5-41	....	....

/1/ 760 mm of mercury (atmospheric pressure), unless otherwise specified. /2/ At temperature indicated in in superscript. /4/ Milligrams KOH required to neutralize one gram of acid. /5/ Grams of iodine absorbed by 100

Contributor: Markley, Klare S.

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Refractive Index[3] $n\frac{^\circ C}{D}$ (H)	Neutralization Value[4] (I)	Iodine Value (Calculated)[5] (J)	Solubility (K)	Source (L)	Reference (M)	
			Hydroxy Unsaturated Acids			
....	189.2	171.2	s.acet., al., pent.	*Tragopogon porrifolius* seed oil	8	136
....	190.5	258.6	....	Kamala-seed oil	29	137
....	190.5	258.6	....	Elaidinized α-acid	29	138
			Branched-Chain Fatty Acids			
$1.40178^{22.4^\circ}$	549.3	......	s.al., chl., eth.; sl.s.w.	Dolphin & porpoise head oils	13,28,29,36	139
....	354.6	......	s.acet., eth., me.al., pet.eth.	Wool grease	13,29,36,40	140
....	301.2	......	s.acet., eth., me.al., pet.eth.	Wool grease	13,29,36,40	141
....	280.1	......	s.acet., eth., me.al., pet.eth.	Wool grease	13,29,36,40	142
1.4424^{25°	261.8	......	s.bz., chl., me.al., pet.eth.	Wool grease, butter, mutton tallow	13,29,36,40	143
1.4293^{60°	261.8	......	s.acet., al., me.al., pet.eth.	Butterfat	29	144
....	245.7	......	s.acet., me.al., pet.eth.	Wool grease, butterfat	13,29,36,40	145
1.4327^{59°	231.5	......	s.chl., eth., me.al., pet.eth.	Wool grease, butter, mutton tallow	13,29,36,40	146
1.4312^{59°	231.5	......	s.me.al., pet.eth.	Butterfat	29	147
1.4293^{70°	218.8	......	s.acet., eth., me.al., pet.eth.	Wool grease, butterfat	13,29,36,40	148
....	207.5	......	s.acet., eth., me.al., pet.eth.	Wool grease, mutton tallow	13,29,36,40	149
1.4315^{70°	207.5	......	s.acet., eth., pet.eth.	Wool grease, beef tallow	13,29,36,40	150
....	197.2	......	s.acet., glac.ac.a.	Butterfat	20	151
....	197.2	......	s.acet., eth., pet.eth.	Wool grease	13,29,36,40	152
1.4512^{25°	188.0	......	s.acet., al., me.al., pent.	Human tubercle bacilli lipids	13,29,36	153
....	188.0	......	s.acet., me.al., pet.eth.	Wool grease	13,29,35,36, 40	154
....	179.5	......	s.al., eth., pet.eth.	Wool grease	13,29,36,40	155
....	171.8	......	s.acet., chl., pet.eth.	Wool grease	13,29,36,40	156
....	164.7	......	s.chl., eth., me.al., pet.eth.	Wool grease	13,29,36,40	157
....	158.2	......	s.acet., chl., eth., pet.eth.	Wool grease	13,29,36,40	158
....	152.2	......	s.acet., chl., pet.eth.	Wool grease	13,29,36,40	159
....	146.6	......	s.al., bz., chl., pet.eth.	Wool grease	13,29,36,40	160
....	141.4	......	s.acet., chl., glac.ac.a.	Wool grease	13,29,36,40	161
....	136.6	......	s.bz., chl., glac.ac.a., pet.eth.	Wool grease	13,29,36,40	162
....	132.1	......	s.bz., chl., glac.ac.a., pet.eth.	Wool grease	13,29,36,40	163
....	120.2	......	s.bz., chl., glac.ac.a., pet.eth.	Wool grease	13,29,36,40	164
....	120.2	......	s.chl., pet.eth.	Tubercle bacilli lipids	13,29	165
1.4434^{47°	560.4	253.6	v.s.eth.; s.al.; sl.s.w.	*Angelica* root & Roman camomile oils	29	166
1.4342^{81°	560.4	253.6	v.s.h.w.; s.al., eth.	*Croton tiglium* root & Roman camomile oils	29	167
....	491.6	222.4	s.al., chl., eth.	*Calotropis procera* sap	29	168
1.4598^{25°	137.3	62.1	s.acet., me.al., pet.eth.	Tubercle bacilli lipids	29	169

superscript, referred to water at 4°C. /3/ Refractive index *(n)* is given for the sodium D-line at temperature shown grams of acid.

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101. FATS AND OILS: PHYSICAL

Values are typical rather than average, and frequently were derived from specific analyses for particular samples
source, treatment, and age of a fat or oil. **Specific Gravity** (column D) was calculated at the specified temperature
parentheses (column D), was measured at the specified temperature (degrees centrigrade). **Refractive Index** (column

	Fat or Oil	Source	Constants				
			Melting (or Solidification) Point, °C	Specific Gravity (or Density)	Refractive Index $n_D^{40°C}$	Iodine Value	Saponification Value
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Land Animals						
1	Butterfat	*Bos taurus*	32.2	$0.911^{40°/15°}$	1.4548	36.1	227
2	Depot fat	*Homo sapiens*	(15)	$0.918^{15°}$	1.4602	67.6	196.2
3	Lard oil	*Sus scrofa*	(30.5)	$0.919^{15°}$	1.4615	58.6	194.6
4	Neat's-foot oil	*B. taurus*	.....	$0.910^{25°}$	$1.464^{25°}$	69-76	190-199
5	Tallow, beef	*B. taurus*	.....	....	....	49.5	197
6	Tallow, mutton	*Ovis aries*	(42.0)	$0.945^{15°}$	1.4565	40	194
	Marine Animals						
7	Cod-liver oil	*Gadus morhua*	.....	$0.925^{25°}$	$1.481^{25°}$	165	186
8	Herring oil	*Clupea harengus*	.....	$0.900^{60°}$	$1.4610^{60°}$	140	192
9	Menhaden oil	*Brevoortia tyrannus*	.....	$0.903^{60°}$	$1.4645^{60°}$	170	191
10	Sardine oil	*Sardinops caerulea*	.....	$0.905^{60°}$	$1.4660^{60°}$	185	191
11	Sperm oil, body	*Physeter macrocephalus*	.....	....	....	76-88	122-130
12	Sperm oil, head	*P. macrocephalus*	.....	....	....	70	140-144
13	Whale oil	*Balaena mysticetus*	.....	$0.892^{60°}$	$1.460^{60°}$	120	195
	Plants						
14	Babassu oil	*Attalea funifera*	22-26	$(0.893^{60°})$	$1.443^{60°}$	15.5	247
15	Castor oil	*Ricinus communis*	(-18.0)	$0.961^{15°}$	1.4770	85.5	180.3
16	Cocoa butter	*Theobroma cacao*	34.1	$0.964^{15°}$	1.4568	36.5	193.8
17	Coconut oil	*Cocos nucifera*	25.1	$0.924^{15°}$	1.4493	10.4	268
18	Corn oil	*Zea mays*	(-20.0)	$0.922^{15°}$	1.4734	122.6	192.0
19	Cottonseed oil	*Gossypium hirsutum*	(-1.0)	$0.917^{25°}$	1.4735	105.7	194.3
20	Linseed oil	*Linum usitatissimum*	(-24.0)	$0.938^{15°}$	$1.4782^{25°}$	178.7	190.3
21	Mustard oil	*Brassica hirta*	.....	$0.9145^{15°}$	1.475	102	174
22	Neem oil	*Melia azadirachta*	-3	$0.917^{15°}$	1.4615	71	194.5
23	Niger-seed oil	*Guizotia abyssinica*	.....	$0.925^{15°}$	1.471	128.5	190
24	Oiticica oil	*Licania rigida*	.....	$0.974^{25°}$	....	140-180	....
25	Olive oil	*Olea europaea sativa*	(-6.0)	$0.918^{15°}$	1.4679	81.1	189.7
26	Palm oil	*Elaeis guineensis*	35.0	$0.915^{15°}$	1.4578	54.2	199.1
27	Palm-kernel oil	*E. guineensis*	24.1	$0.923^{15°}$	1.4569	37.0	219.9
28	Peanut oil	*Arachis hypogaea*	(3.0)	$0.914^{15°}$	1.4691	93.4	192.1
29	Perilla oil	*Perilla frutescens*	.....	$(0.935^{15°})$	$1.481^{25°}$	195	192
30	Poppy-seed oil	*Papaver somniferum*	(-15)	$0.925^{15°}$	1.4685	135	194
31	Rapeseed oil	*Brassica campestris*	(-10)	$0.915^{15°}$	1.4706	98.6	174.7
32	Safflower oil	*Carthamus tinctorius*	.....	$(0.900^{60°})$	$1.462^{60°}$	145	192
33	Sesame oil	*Sesamum indicum*	(-6.0)	$0.919^{25°}$	1.4646	106.6	187.9
34	Soybean oil	*Glycine soja*	(-16.0)	$0.927^{15°}$	1.4729	130.0	190.6
35	Sunflower-seed oil	*Helianthus annuus*	(-17.0)	$0.923^{15°}$	1.4694	125.5	188.7
36	Tung oil	*Aleurites fordi*	(-2.5)	$0.934^{15°}$	$1.5174^{25°}$	168.2	193.1
37	Wheat-germ oil	*Triticum aestivum*	.....	....	....	125	....

/1/ Caproic. /2/ Caprylic. /3/ Capric. /4/ Butyric. /5/ Decenoic. /6/ C_{12} monoethenoic. /7/ C_{14} monoethenoic.
polyethenoic. /13/ C_{22} polyethenoic. /14/ Behenic. /15/ C_{14} polyethenoic. /16/ Gadoleic. /17/ C_{24} polyethenoic.
cludes behenic. /24/ Licanic. /25/ Eleostearic.

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(especially the constituent fatty acids). Extreme variations may occur, depending on a number of variables such as (degrees centigrade) and referred to water at the same temperature, unless otherwise specified. **Density**, shown in E) was measured at 40°C, unless otherwise specified.

Constituent Fatty Acids, g/100 g total fatty acids												
Saturated						Unsaturated						
Lauric	Myristic	Palmitic	Stearic	Arachidic	Other	Palmitoleic	Oleic	Linoleic	Linolenic	Other		
(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)	(P)	(Q)	(R)	No.	
2.5	11.1	29.0	9.2	2.4	2.0[1]; 0.5[2]; 2.3[3]	4.6	26.7	3.6	....	3.6[4]; 0.1[5]; 0.1[6]; 0.9[7]; 1.4[8]; 1.0[9]; 1.0[10]; 0.4[11]	1	
....	2.7	24.0	8.4	....	....	5	46.9	10.2	....	2.5[8]	2	
....	1.3	28.3	11.9	....	....	2.7	47.5	6	....	0.2[7]; 2.1[8]	3	
....	.....	17-18	2-3	....	....	....	74-76	....	....	....	4	
....	6.3	27.4	14.1	....	....	....	49.6	2.5	....	....	5	
....	4.6	24.6	30.5	....	....	....	36.0	4.3	....	....	6	
....	5.8	8.4	0.6	....	....	20.0	← 29.1 →		....	25.4[12]; 9.6[13]	7	
....	7.3	13.0	Trace	....	....	4.9	....	....	20.7	30.1[12]; 23.2[13]	8	
....	5.9	16.3	0.6	0.6	....	15.5	....	....	29.6	19.0[12]; 11.7[13]; 0.8[14]	9	
....	5.1	14.6	3.2	....	....	11.8	← 17.8 →		....	18.1[12]; 14.0[13]; trace[7]; 15.4[15]	10	
1	5	6.5	.....	....	....	26.5	37	19	....	1[13]; 4[7]; 19[16]	11	
16	14	8	2	....	3.5[3]	15	17	6.5	....	4[6]; 14[7]; 6.5[16]	12	
0.2	9.3	15.6	2.8	....	....	14.4	35.2	....	....	13.6[12]; 5.9[13]; 2.5[7]; 0.2[17]	13	
44.1	15.4	8.5	2.7	0.2	0.2[1]; 4.8[2]; 6.6[3]	....	16.1	1.4	....	....	14	
← 2.4 →				....	....	....	7.4	3.1	....	87[18]	15	
....	.....	24.4	35.4	....	....	....	38.1	2.1	....	....	16	
45.4	18.0	10.5	2.3	0.4[19]	0.8[1]; 5.4[2]; 8.4[3]	0.4	7.5	Trace	....	....	17	
....	1.4	10.2	3.0	....	....	1.5	49.6	34.3	....	....	18	
....	1.4	23.4	1.1	1.3	....	2.0	22.9	47.8	....	....	19	
....	.....	6.3	2.5	0.5	....	....	19.0	24.1	47.4	0.2[14]	20	
....	1.3[20]	.....	.....	....	....	....	27.2[20]	16.6[20]	1.8[20]	1.1[14]; 1.0[21]; 51.0[22]	21	
....	2.6[20]	14.1[20]	24.0[20]	0.8[20]	....	....	58.5[20]	....	....	....	22	
....	3.3[20]	8.2[20]	4.8[20]	0.5[20]	....	....	30.3[20]	57.3[20]	....	....	23	
← 11.3[23] →					....	....	6.2	....	....	82.5[24]	24	
....	Trace	6.9	2.3	0.1	....	....	84.4	4.6	....	....	25	
....	1.4	40.1	5.5	....	....	....	42.7	10.3	....	....	26	
46.9	14.1	8.8	1.3	....	2.7[2]; 7.0[3]	....	18.5	0.7	....	....	27	
....	.....	8.3	3.1	2.4	....	....	56.0	26.0	....	3.1[14]; 1.1[21]	28	
← 9.6[23] →					....	....	17.8	....	17.5	....	29	
....	.....	4.8[20]	2.9[20]	....	....	....	30.1[20]	62.2[20]	....	....	30	
....	.....	1	.....	....	....	....	32	15	1	50[22]	31	
← 6.8[23] →					....	....	18.6	70.1	3.4	....	32	
....	.....	9.1	4.3	0.8	....	....	45.4	40.4	....	....	33	
0.2	0.1	9.8	2.4	0.9	....	0.4	28.9	50.7	6.5	0.1[7]	34	
....	.....	5.6	2.2	0.9	....	....	25.1	66.2	....	....	35	
← 4.6[23] →					....	....	4.1	0.6	....	90.7[25]	36	
← 16.0[23] →					....	....	28.1	52.3	3.6	....	37	

/8/ Gadoleic plus erucic. /9/ C_{12} n-pentadecanoic. /10/ C_{17} margaric. /11/ 12-Methyl tetradecanoic. /12/ C_{20}
/18/ Ricinoleic. /19/ Includes behenic and lignoceric. /20/ Percent by weight. /21/ Lignoceric. /22/ Erucic. /23/ In-

continued

101. FATS AND OILS: PHYSICAL AND CHEMICAL CHARACTERISTICS

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102. WAXES: PHYSICAL AND CHEMICAL CHARACTERISTICS

Specific Gravity (column C) was calculated at the specified temperature, degrees centigrade, and referred to water at the same temperature. **Density**, shown in parentheses (column C), and **Refractive Index** (column D) were measured at the specified temperature, degrees centigrade.

	Wax	Melting Point °C	Specific Gravity or (Density)	Refractive Index $n_D^{°C}$	Iodine Value	Acid Value	Saponification Value	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
1	Bamboo leaf	79-80	(0.961$^{25°}$)	....	7.8[1]	14.5	43.4	9
2	Bayberry (myrtle)	46.7-48.8	(0.985$^{15°}$)	1.436$^{80°}$	2.9[2]-3.9[3]	3.5	20.5-21.7	7,10
3	Beeswax, crude	62-66	(0.927-0.970$^{15°}$)	1.439-1.483$^{40°}$	6.8-16.4[2]	16.8-35.8	89.3-149.0	10
4	Beeswax, white, U.S.P.	61-69	(0.959-0.975$^{15°}$)	1.447-1.465$^{65°}$	7-11[3]	17-24	90-96	10
5	Beeswax, yellow	62-65	(0.960-0.964$^{15°}$)	1.443-1.449$^{65°}$	6-11	18-24	90-97	10
6	Candelilla, refined	67-69	(0.982-0.986$^{15°}$)	1.454-1.463$^{85°}$	14.4-20.4	12.7-18.1	35-86	1
7	Cape berry[4]	40.5-45.0	(1.004-1.007$^{15°}$)	1.450$^{45°}$	0.6-2.4	2.5-3.7	211-215	10
8	Carandá	79.7-84.5	(0.990$^{25°}$)	....	8.0-8.9	5.0-9.5	64.5-78.5	2,10
9	Carnauba	83-86	0.990-1.001$^{15°}$	1.467-1.472$^{40°}$	7.2-13.5	2.9-9.7	78-95	10
10	Castor oil, hydrogenated	83-88	(0.980-0.990$^{20°}$)	....	2.5-8.5	1.0-5.0	177-181	6,10
11	Chinese insect	81.5-84.0	0.950-0.970$^{15°}$	1.457$^{40°}$	1.4	0.2-1.5	73-93	10
12	Cotton	68-71	0.959$^{15°}$	....	24.5	32	70.6	8
13	Cranberry	207-218	(0.970-0.975$^{15°}$)	....	44.2-53.2[2]	42.2-59.1	131-134	10
14	Douglas-fir bark	59.0-72.8	(1.030$^{25°}$)	1.468$^{80°}$	25.8-62.5	58.6-80.7	112-200	10
15	Esparto	67.5-78.1	0.988$^{15°}$	....	22-23	22.7-23.9	69.8-79.3	10
16	Flax	61.5-69.8	0.908-0.985$^{15°}$	....	21.6-28.8	17.5-48.3	77.5-101.5	10
17	Ghedda, E. Indian beeswax	60.5-66.4	0.956-0.973$^{15°}$	1.440$^{50°}$	5.6-12.6	5.8-7.9	84.5-118.3	10
18	Indian corn	80-81	....	....	4.2[2]	1.9	120.3	5
19	Japan wax	48-53	0.975-0.993$^{15°}$	....	4.5-12.5	6-20	206.5-237.5	10
20	Jojoba	11.2-11.8	0.864-0.899$^{25°}$	1.465$^{25°}$	81.7-88.4[2]	0.2-0.6	92.2-95.0	10
21	Madagascar	88	....	....	3.2-5.3	17.7-28.0	140.0-159.6	10
22	Microcrystalline, amber	64-91	0.913-0.943$^{15°}$	1.424-1.452$^{80°}$	0	0	0	10
23	Microcrystalline, white	71-89	0.928-0.941$^{15°}$	1.441$^{80°}$	0	0	0	10
24	Montan, crude	76-86	(1.010-1.020$^{25°}$)	....	13.9-17.6	22.7-31.0	59.4-92.0	10
25	Montan, refined	77-84	(1.010-1.030$^{25°}$)	....	10-14	24-43	72-103	10
26	Orange peel	44.0-46.5	0.985$^{15°}$	1.502$^{20°}$	115.7[2]	48.3	120.9	4
27	Ouricury, refined	79.0-83.8	1.053$^{15°}$	....	6.9-7.8[2]	3.4-21.1	61.8-85.8	10
28	Ozocerite, refined	74.4-75.0	0.907-0.920$^{15°}$	....	0	0	0	10
29	Palm	74-86	(0.991-1.045$^{15°}$)	....	8.9-16.9[2]	5.0-10.6	64.5-104.0	10
30	Paraffin, American	49-63	0.896-0.925$^{15°}$	1.442-1.448$^{80°}$	0	0	0	10
31	Peat wax, natural	73-76	0.980$^{15°}$	....	16-40	60.0-73.3	73.9-136.0	10
32	Rice bran, refined	75.3-79.9	....	1.469$^{30°}$	11.1-19.4	15-17	56.9-104.4	10
33	Shellac wax	79-82	0.971-0.980$^{15°}$	....	6.0-8.8[3]	12.1-24.3	63.8-83.0	10
34	Sisal hemp	74-81	1.007-1.010$^{15°}$	....	28-29[2]	16-19[2]	56-58	10
35	Sorghum grain	77-82	....	....	15.7-20.9	10.1-16.2	16-44	10
36	Spanish moss	79-80	....	....	33.0	25.0	120.4	3
37	Spermaceti	42-50	0.905-0.945$^{15°}$	1.440$^{70°}$	4.8-5.9	2.0-5.2	108-134	10
38	Sugarcane, crude	52-67	0.988-0.998$^{25°}$	....	32-84	24-57	128-177	10
39	Sugarcane, double-refined	77-82	0.961-0.979$^{25°}$	1.510$^{25°}$	13-29	8-23	55-95	10
40	Wool wax, refined	36-43	0.932-0.945$^{15°}$	1.478-1.482$^{40°}$	15.0-46.9	5.6-22.0	80-127	10

/1/ Wijs test. /2/ Hanus test. /3/ Hubl test. /4/ *Myrica cordifolia.*

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103. PHOSPHATIDES AND CEREBROSIDES: PHYSICAL AND CHEMICAL CHARACTERISTICS

Data are for synthetic lipids containing known fatty acids. Naturally occurring lipids contain a spectrum of fatty acids [11-13, 16-23, 26] and have different properties dependent on their fatty-acid composition. **Solubility** (column F): ac.a. = acetic acid; acet. = acetone; bz. = benzene; c.tet. = carbon tetrachloride; chl. = chloroform; die. = diethyl; e.acet. = ethyl acetate; e.al. = ethanol; eth. = ether; ethy. = ethylene; glac. = glacial; gly. = glycol; i. = insoluble; me.al. = methanol; monome. = monomethyl; pet. = petroleum; pyr. = pyridine; sl. = slightly; s. = soluble; v. = very; w. = water.

	Lipid	Chemical Formula	Molecular Weight	Melting Point °C	Specific Rotation $[\alpha]_D$	Solubility	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Phosphatidylcholines (Lecithins)						
1	Dihexanoyl-L-α-phosphatidylcholine	$C_{20}H_{42}O_9NP$	471.5	....	+10.9 in chloroform	v.s.acet., chl., e.al., me.al., w.; i.die.eth.	7
2	Dioctanoyl-L-α-phosphatidylcholine	$C_{24}H_{50}O_9NP$	527.6	....	+9.65 in chloroform-methyl alcohol (1:1)	v.s.acet., chl., e.al., me.al.; i.die.eth.	7
3	Didecanoyl-L-α-phosphatidylcholine	$C_{28}H_{58}O_9NP$	583.7	....	+8.75 in chloroform-methyl alcohol (1:1)	v.s.chl., e.al., me.al.; s.acet.; i.die.eth.	7
4	Dimyristoyl-L-α-phosphatidylcholine	$C_{36}H_{74}O_9NP$	695.9	237-237.5	+7.0 in chloroform-methyl alcohol (1:1)	v.s.me.al., pyr.; s.acet.; i.w.	6
5	Dipalmitoleyl-L-α-phosphatidylcholine	$C_{40}H_{78}O_9NP$	748.1	....	+6.6 in chloroform-methyl alcohol (1:1)	v.s. 90% acet., chl., e.al., me.al.; i.pet.eth., w.	14
6	Dipalmitoyl-L-α-phosphatidylcholine	$C_{40}H_{82}O_9NP$	752.1	234-235	+6.6 in chloroform-methyl alcohol (1:1)	v.s.me.al., pyr.; s.acet.; i.w.	6
7	Dioleyl-L-α-phosphatidylcholine	$C_{44}H_{86}O_9NP$	804.1	....	+6.2 in chloroform-methyl alcohol (1:1)	v.s. 90% acet., die.eth., e.al., me.al.; s.pet.eth.	5
8	Distearoyl-L-α-phosphatidylcholine	$C_{44}H_{90}O_9NP$	808.2	230.5-231.5	+6.1 in chloroform-methyl alcohol (1:1)	s.me.al., pyr.; sl.s.acet.; i.w.	6
	Phosphatidylethanolamines (Cephalins)						
9	Dimyristoyl-L-α-phosphatidylethanolamine	$C_{33}H_{66}O_8NP$	635.9	195-196	+6.7 in chloroform	v.s.chl.; s.bz., c.tet., e.al., pyr.; i.acet., die.eth., e.acet., pet.eth.	8
10	Dipalmitoyl-L-α-phosphatidylethanolamine	$C_{37}H_{74}O_8NP$	692.0	186-187	+6.4 in chloroform	v.s.chl.; s.bz., c.tet., e.al., pyr.; i.acet., die.eth., e.acet., pet.eth.	8
11	Dioleyl-L-α-phosphatidylethanolamine	$C_{41}H_{78}O_8NP$	744.1	....	+6.0 in chloroform	v.s.acet., chl., die.eth., e.al., pet.eth.; i.w.	4
12	Distearoyl-L-α-phosphatidylethanolamine	$C_{41}H_{82}O_8NP$	748.1	180-182	+6.0 in chloroform-acetic acid (1:1)	v.s.chl.; s.bz., c.tet., e.al., pyr.; i.acet., die.eth., e.acet., pet.eth.	8
	Phosphatidylserines						
13	Distearoyl-L-α-phosphatidylserine	$C_{42}H_{82}O_{10}NP$	792.1	159-161	-14.0 in chloroform	s.bz., chl.; i.w.	9
	Phosphatidylglycerols						
14	(Dioleyl-L-α-glycerylphosphoryl)-L-α-glycerol	$C_{42}H_{79}O_{10}P$	775.0	....	+2.0 in chloroform	v.s.acet., bz., chl., die.eth., e.al., ethy.gly. monome.eth., me.al., pet.eth.; i.w.	3
15	(Distearoyl-L-α-glycerylphosphoryl)-L-α-glycerol	$C_{42}H_{83}O_{10}P$	779.1	66.5-67.0	+2.0 in chloroform	v.s.acet., bz., chl., die.eth., e.al., ethy.gly. monome.eth., me.al., pet.eth.	3

continued

103. PHOSPHATIDES AND CEREBROSIDES: PHYSICAL AND CHEMICAL CHARACTERISTICS

	Lipid	Chemical Formula	Molecular Weight	Melting Point °C	Specific Rotation $[\alpha]_D$	Solubility	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Phosphatidylinositols						
16	Beef liver monophosphoinositide	....	.....	....	+5.86 in chloroform	v.s.w.; s.chl., chl./e.al. (3/1), e.acet., glac.ac.a.; i.acet., e.al., me.al.	15
	Phosphatidic Acids						
17	Dimyristoyl-L-α-glyceroylphosphoric acid	$C_{31}H_{61}O_8P$	592.8	61.5-62.5	+4.4 in chloroform	v.s.acet., bz., die.eth., e.al., glac.ac.a.	1,10
18	Dipalmitoyl-L-α-glyceroylphosphoric acid	$C_{35}H_{69}O_8P$	648.9	70-71	+4.0 in chloroform	v.s.acet., bz., die.eth., e.al., glac.ac.a.	1,10
19	Dioleyl-L-α-glyceroylphosphoric acid	$C_{39}H_{73}O_8P$	701.0	....	+3.8 in chloroform	v.s.acet., bz., chl., die.eth., 99% e.al., pet.eth.	2
20	Distearoyl-L-α-glyceroylphosphoric acid	$C_{39}H_{77}O_8P$	705.0	75.5-76.5	+3.8 in chloroform	v.s.die.eth., e.al., glac.ac.a.; s.acet., bz.	1,10
	Sphingomyelins						
21	Palmitoylsphingomyelin	$C_{39}H_{81}O_7N_2P$	721.1	209-211			25
22	Stearoylsphingomyelin	$C_{41}H_{85}O_7N_2P$	749.1	209-210			
23	Lignocerylsphingomyelin	$C_{47}H_{97}O_7N_2P$	833.3	213-216			
	Ceramides						
24	*N*-Lignoceryl-D-sphingosine	$C_{42}H_{83}NO_3$	649.8	93-95	-2.0 in chloroform		24
25	*N*-Lignoceryl-D-dihydrosphingosine	$C_{42}H_{85}NO_3$	651.9	102-103	0.0 in pyridine		
	Cerebrosides						
26	*N*-Behenyl-D-sphingosyl-β-D-glucopyranoside (Gaucher's cerebroside)	$C_{46}H_{89}NO_3$	827.9	182-183	-7.6 in pyridine		24
27	*N*-Lignoceryl-D-sphingosyl-β-D-galactopyranoside (cerasine)	$C_{48}H_{93}NO_8$	811.9	182	-3.4 in pyridine		
28	*N*-Cerebronyl-D-sphingosyl-β-D-galactopyranoside (phrenosine)	$C_{48}H_{93}NO_9$	811.9	195	+4.4 in pyridine		

Contributor: O'Brien, John S.

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104. STEROLS: PHYSICAL AND CHEMICAL CHARACTERISTICS

	Substance (Systematic Name)[1,2]	Chemical Formula	Melting Point °C	Specific Rotation[3] $[\alpha]_D$	Source	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
1	($\Delta^{3,5}$-Cholestadien-7-one)	$C_{27}H_{42}O$	112	-305	Testis, spleen (swine); sclerotic aorta	35,63,68
2	($\Delta^{4,6}$-Cholestadien-3-one)	$C_{27}H_{42}O$	80	+35	Sclerotic aorta; spleen (swine)	34,63
3	($\Delta^{5,7,22}$-Cholestatrien-3β-ol)	$C_{27}H_{42}O$	?	?	Shellfish	86
4	(Δ^{4}-Cholesten-3-one)	$C_{27}H_{44}O$	81	+89	Feces; hypophysis, testis (swine)	62,64,65
5	7-Dehydrocholesterol ($\Delta^{5,7}$-Cholestadien-3β-ol)	$C_{27}H_{44}O$	150	-114	Cholesterol; skin (swine); snail	21,94
6	22-Dehydrocholesterol ($\Delta^{5,22}$-Cholestadien-3β-ol)	$C_{27}H_{44}O$	135	-57	Shellfish; red algae	79,83
7	24-Dehydrocholesterol ($\Delta^{5,24(25)}$-Cholestadien-3β-ol)	$C_{27}H_{44}O$	117	-38	Barnacle	28
8	Zymosterol ($\Delta^{8,24}$-Cholestadien-3β-ol)	$C_{27}H_{44}O$	108	+47	Yeast	74,90,92
9	(Cholestane-3,6-dione)	$C_{27}H_{44}O_2$	175	....	Testis (swine)	64
10	7-Ketocholesterol (Δ^{5}-Cholesten-3β-ol-7-one)	$C_{27}H_{44}O_2$	170	-104	Testis (cattle, swine)	63,64
11	Cholesterol[4] (Δ^{5}-Cholesten-3β-ol)	$C_{27}H_{46}O$	149	-39	All animal cells; spinal cord; wool grease; red algae	50
12	Lathosterol[4] (Δ^{7}-Cholesten-3β-ol)	$C_{27}H_{46}O$	122	+5.7	Skin; cholesterol	32,42
13	(Coprostan-3-one)	$C_{27}H_{46}O$	63	+36	Ambergris	49
14	(Δ^{4}-Cholestene-3β,6β-diol)	$C_{27}H_{46}O_2$	258	+9.0	Spleen (swine)	63
15	7α-Hydroxycholesterol (Δ^{5}-Cholestene-3β,7α-diol)	$C_{27}H_{46}O_2$	184	-93	Sclerotic aorta; spleen (swine); serum (pregnant mare)	35,63,96
16	7β-Hydroxycholesterol (Δ^{5}-Cholestene-3β,7β-diol)	$C_{27}H_{46}O_2$	178	+7.2	Liver (cattle, swine); spleen (swine); serum (pregnant mare)	19,37,55,63
17	22-Hydroxycholesterol (Δ^{5}-Cholestane-3β,20α-diol)	$C_{27}H_{46}O_2$	186	-39	Lily	75,84
18	(Cholestan-3β-ol-6-one)	$C_{27}H_{46}O_2$	143	....	Spleen (swine)	63
19	(Cholestane-3β,5α-diol-6-one)	$C_{27}H_{46}O_3$	236	....	Cholesterol; liver (swine)	71
20	Cholestanol[4] (Cholestan-3β-ol)	$C_{27}H_{48}O$	142	+24	Cholesterol; sclerotic aorta	54,69,70
21	Coprostanol (Coprostan-3β-ol)	$C_{27}H_{48}O$	101	+28	Feces	56
22	Epicoprostanol (Coprostan-3α-ol)	$C_{27}H_{48}O$	117	+32	Feces; ambergris	56
23	(Cholestane-3β,5,6β-triol)	$C_{27}H_{48}O_3$	239	+3.2	Liver (cattle); testis (swine); sclerotic aorta	35,38,68
24	Dehydroergosterol ($\Delta^{5,7,9(11),22}$-Ergostatetraen-3β-ol)	$C_{28}H_{42}O$	146	+149	Yeast; ergot	67,93
25	14-Dehydroergosterol ($\Delta^{5,7,14,22}$-Ergostatetraen-3β-ol)	$C_{28}H_{42}O$	198	-396	Mold	8
26	24-Dehydroergosterol ($\Delta^{5,7,22,24(28)}$-Ergostatetraen-3β-ol)	$C_{28}H_{42}O$	118	-78	Yeast	23
27	Fungisterol (Δ^{7}-Ergosten-3β-ol)	$C_{28}H_{44}O$	148	-0.2	Ergot	88
28	Ergosterol ($\Delta^{5,7,22}$-Ergostatrien-3β-ol)	$C_{28}H_{44}O$	165	-130	Ergot; yeast; *Aspergillus niger*	20,29,39,57,77,78
29	22-Dihydroergosterol ($\Delta^{5,7}$-Ergostadien-3β-ol)	$C_{28}H_{46}O$	153	-109	Ergot	66
30	Brassicasterol ($\Delta^{5,22}$-Ergostadien-3β-ol)	$C_{28}H_{46}O$	148	-64	Rapeseed; invertebrates	16
31	24-Methylenecholesterol[5] ($\Delta^{5,24(28)}$-Ergostadien-3β-ol)	$C_{28}H_{46}O$	144	-42	Sponge; mollusks; honeybee	10,17,27,43,44
32	5-Dihydroergosterol ($\Delta^{7,22}$-Ergostadien-3β-ol)	$C_{28}H_{46}O$	174	-20	Yeast	6,7,24
33	($\Delta^{7,24(28)}$-Ergostadien-3β-ol)	$C_{28}H_{46}O$	131	+6.0	Starfish	29
34	Episterol ($\Delta^{7,24(28?)}$-Ergostadien-3β-ol)	$C_{28}H_{46}O$	151	-5	Yeast	6,7,89,91
35	Ascosterol ($\Delta^{8,23(?)}$-Ergostadien-3β-ol)	$C_{28}H_{46}O$	147	+45	Yeast	90-92
36	Fecosterol ($\Delta^{8,24(28)}$-Ergostadien-3β-ol)	$C_{28}H_{46}O$	162	+42	Yeast	90,92
37	Cerevisterol ($\Delta^{7,22}$-Ergostadiene-3β,5α,6β-triol)	$C_{28}H_{46}O_3$	265	-79	Yeast; ergot	41,88
38	Haliclonasterol	$C_{28}H_{48}O$	141	-41.5	Sponge; green algae	11
39	Campesterol (Δ^{5}-24-Isoergosten-3β-ol)	$C_{28}H_{48}O$	158	-33	Rapeseed; soybean; wheat germ	30

/1/ The numbers after the symbol "Δ" indicate the position of double bonds in the basic cyclopentano perhydrophenanthrene ring. /2/ Methyl sterols not included. /3/ Chloroform solvent for most determinations. /4/ Also isolated from invertebrates. /5/ Earlier preparations containing this substance referred to as chalinasterol and ostreasterol.

continued

104. STEROLS: PHYSICAL AND CHEMICAL CHARACTERISTICS

	Substance (Systematic Name)[1,2]	Chemical Formula	Melting Point °C	Specific Rotation[3] $[\alpha]_D$	Source	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
40	Neospongosterol (Δ^{22}-24-Isoergosten-3β-ol)	$C_{28}H_{48}O$	153	+10	Sponge	14
41	Fucosterol ($\Delta^{5,24(28)}$-Stigmastadien-3β-ol)	$C_{28}H_{48}O$	124	-38	Brown algae	35,40
42	Aptostanol	$C_{28}H_{50}O$	135	+22	Sponge	18
43	Ergostanol (Ergostan-3β-ol)	$C_{28}H_{50}O$	143	+16	Plant	47
44	β-Sitosterol (Δ^{5}-Stigmasten-3β-ol)	$C_{29}H_{50}O$	140	-36	Cottonseed; calycanthus seed; cinchona bark; wheat germ; rubber; invertebrates	3,5,25,51, 52,87
45	Corbisterol ($\Delta^{5,7,22}$-Stigmastadien-3β-ol)	$C_{29}H_{46}O$	154	-114	Shellfish	58,80
46	Chondrillasterol ($\Delta^{7,22}$-24-Isoergostadien-3β-ol)	$C_{29}H_{48}O$	164	-2	Green algae; sponge	12,15
47	Poriferasterol ($\Delta^{5,22}$-24-Isostigmastadien-3β-ol)	$C_{29}H_{48}O$	156	-49	Sponge; shellfish	53,69,81,85
48	Sargasterol ($\Delta^{5,24(28)}$-20-Isostigmastadien-3β-ol)	$C_{29}H_{48}O$	133.5	-47.5	Algae	82
49	Δ^{5}-Avenasterol ($\Delta^{5,11(?)}$-Stigmastadien-3β-ol)	$C_{29}H_{48}O$	137	-37.6	Oats	46
50	Δ^{7}-Avenasterol ($\Delta^{7,11(?)}$-Stigmastadien-3β-ol)	$C_{29}H_{48}O$	145	+8.8	Oats	46
51	Stigmasterol ($\Delta^{5,22}$-Stigmastadien-3β-ol)	$C_{29}H_{48}O$	170	-49	Calabar bean; soybean	61,95
52	α-Spinasterol ($\Delta^{7,22}$-Stigmastadien-3β-ol)	$C_{29}H_{48}O$	175	-2.7	Spinach; senega root; alfalfa; colocynth; starfish	26,31,34-36, 73
53	Palysterol	$C_{29}H_{50}O$	140	-47	Sea anemone	13
54	Clionasterol (Δ^{5}-24-Isostigmasten-3β-ol?)	$C_{29}H_{50}O$	138	-37	Sponge; shellfish	48,59,69,81
55	γ-Sitosterol (Δ^{5}-24-Isostigmasten-3β-ol)	$C_{29}H_{50}O$	148	-43	Soybean; wheat germ; rye germ	5,9,22,33
56	(Δ^{7}-Stigmasten-3β-ol)	$C_{29}H_{50}O$	145	+9	Wheat germ; starfish	45
57	Dihydrositosterol (Stigmastan-3β-ol)	$C_{29}H_{52}O$	140	+25	Grains	1-5,60
58	(Δ^{22}-Stigmastan-3β-ol)	$C_{29}H_{52}O$	159	+3.3	Root	76
59	Dicholesteryl ether	$C_{54}H_{90}O$	196	-38	Spinal cord	72

/1/ The numbers after the symbol "Δ" indicate the position of double bonds in the basic cyclopentano perhydrophenanthrene ring. /2/ Methyl sterols not included. /3/ Chloroform solvent for most determinations.

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105. PROTEINS: PHYSICAL AND CHEMICAL CHARACTERISTICS

Method (column C): l = light scattering; s = sedimentation velocity; d = diffusion constant; e = sedimentation equilibrium; o = osmotic pressure; x = X-ray diffraction; v = intrinsic viscosity; a = chemical analysis or combining ratio.

	Protein	Source	Molecular Weight: Method	Molecular Weight: Value	Sedimentation Coefficient[1]	Partial Specific Volume[2]	Isoelectric Point pH[3] (Ionic Strength)	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
1	G-Actin	Rabbit muscle	l	80,000	3.7	......	4.5	89,108
2	Adrenocorticotropic hormone	Sheep hypophysis	sd	20,000	2.0	0.75[4]	4.6-4.7(0.1)	53,54
3	Aldolase	Rabbit muscle	sd?	147,000	7.9	0.740	6.05(0.2)-7.7(0.02)	6,119,120,128
4	Amandin	Almond	e	208,000	11.4	0.746	....	116
5	α-Amylase	Barley malt	o	60,000	....	......	6	99
6	β-Amylase	Sweet potato	sd	150,000	8.9	0.749[4]	4.74-4.79(0.1)	24
7	Bence-Jones	Human urine[5]	e; sd	35,000-37,000	3.55	0.749	5.18	115
8	Botulinum toxin, type A	*Clostridium botulinum*	sd	900,000[6]	17	0.75	....	90
9	Botulinum toxin, type B	*C. botulinum*	sd	500,000	....	......	....	131
10	Bushy stunt virus	Tomato[5]	x	10,800,000	132	0.739	4.11(0.02)	7,51,65,73
11	Carbonic anhydrase	Cattle blood	sd	30,000	2.8	0.749[4]	5.3(0.1)	85
12	Carboxypeptidase	Cattle pancreas	sd; vd	32,000-34,000	3.07	0.75[4]	6.0(0.2)	91,106
13	Cardiotoxin	Cobra venom	d	46,000	....	0.75[4]	....	94
14	Casein (caseinogen)	Cow milk	o	33,600	10.4	0.728	4.6(0.0025-0.01)	14,66,70,82
15	Catalase	Human blood	s; a	220,000	11.2-11.3	0.73[4]	....	17,37
16	Chorionic gonadotropin	Human urine[7]	sd	100,000	4.3	0.76	....	63
17	α-Chymotrypsin	Cattle pancreas	sd; sv	22,500	2.4-2.7	0.73	8.1(0.1)-8.6(0.01)	5,96,98
18	α-Chymotrypsinogen	Cattle pancreas	sd; sv	22,500	2.5	0.72	9.5(0.01)	5,97
19	Colostrum globulin, immune	Cow colostrum	d	160,000-190,000	7	......	5.85(0.1)	103,105
20	Conalbumin	Chicken egg white	a	70,000-77,000	....	......	6.8(0.1)	133
21	Concanavalin A	Jack bean	sd	96,000	6.0	0.73	....	111
22	Crotoxin	Rattlesnake venom	e; sd	30,000	3.1	0.704	4.7(0.1)	32,56
23	Cytochrome-*c*	Cattle or horse heart	sd	16,000	1.9	0.707	10.65[8](0.1)	114,121-123
24	Diphtheria antitoxin	Horse plasma	sd	180,000	7.2	0.745[4]	6.0	80,86
25	Diphtheria toxin	*Corynebacterium diphtheriae*	sd	74,000	4.6	0.736	4.1(0.005)[9]	79,86
26	Edestin	Hemp seed	sd	310,000	12.8	0.745	5.5[10]	2,113,117
27	Enolase	Yeast	e	67,000	5.8	......	....	21
28	Excelsin	Brazil nut	o; e	210,000	11.8	0.743	....	13,116
29	Fetuin	Fetal calf or sheep blood	sd	50,000	3.1-3.4	0.70	3.5(0.2)	84
30	Fibrinogen	Human blood	o; sv	400,000-580,000	9	......	5.4(0.1)	76,109
31	Fumarase	Swine heart	e	220,000	9.1	......	....	21
32	Gelatin	Collagenous tissues	o	5,000-400,000	....	......	4.9(0.01)	1,5
33	Gliadin	Wheat	e	27,000	2.1	0.71	6.5[10]	46,118
34	Globin	Horse blood	a	31,000[11]	2.5	0.749	7.5(0.1)[12]	31,72
35	α-Globulin	Barley	sd	26,000	2.5	0.72	5.0(0.1)	92
36	γ-Globulin	Barley	sd	170,000	8.3	......	5.7(0.1)	92
37	Gluten	Wheat	e	39,000-4,600,000	2.5	0.700	7	64,118
38	α-Glycerolphosphate dehydrogenase	Rabbit muscle	e	78,000-87,000	4.9	......	....	21
39	Glycerol-3-phosphate dehydrogenase	Rabbit muscle	e	140,000	7.7	......	....	21

/1/ Specific sedimentation velocity in units of 10^{-13}, under standard conditions of water at 20°C. /2/ Cubic centimeters increase in volume of solution per gram of protein dissolved. /3/ pH at which protein does not move in an electric field. /4/ Assumed value. /5/ Pathological. /6/ At pH 7.5, dissociation product has molecular weight of 70,000 [130,132]. /7/ During pregnancy. /8/ At 0°C for the oxidized (ferri-)form. /9/ By cataphoresis. /10/ Based on solubility minimum. /11/ Composed of two approximately equal subunits. /12/ For human globin.

continued

105. PROTEINS: PHYSICAL AND CHEMICAL CHARACTERISTICS

	Protein	Source	Molecular Weight		Sedimentation Coefficient[1]	Partial Specific Volume[2]	Isoelectric Point pH[3] (Ionic Strength)	Reference
			Method	Value				
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
40	Growth hormone	Beef hypophysis	a; sd	39,000-49,000	3.1-3.7	0.76	6.85(0.1)	52,55,59,107
41	Hemocyanin	*Helix pomatia*	sd	8,900,000	103	0.738	5.05(0.02)	11,125
42	Hemoglobin A[13]	Human blood	a	64,450	4.5	0.749[14]	6.87(0.1)	10,31,38,81, 95,114
43	Hexokinase	Baker's yeast	sd	97,000	3.1	0.740[4]	4.5-4.8(0.02 M)[9]	47
44	Insulin[15]	Beef pancreas	o; sd	36,000	3.5	0.707	5.2(0.033)	27,33,39,77, 102,136
45	α-Lactalbumin	Cow milk	sd	15,000	1.75	0.735	....	30
46	Lactate dehydrogenase	Rabbit muscle	e	135,000	6.9	......	....	21
47	Lactogenic hormone	Cattle or sheep hypophysis	o	26,500	....	......	5.7(0.05)	57,58
48	β-Lactoglobulin A[16]	Cow milk	x	17,500	2.25	0.751	5.09	12,45,83,101, 126,127
49	Lactoglobulin, immune	Cow milk	sd	180,000	7	......	5.8(0.1)	4,104
50	α-Lipovitellin	Egg yolk	sd	400,000	10.9	0.777	....	8
51	β-Lipovitellin	Egg yolk	sd	400,000	10.4	0.777	....	8
52	α-Livetin	Egg yolk	s	67,000	4.4	......	....	69
53	β-Livetin	Egg yolk	s	45,000	3.0	......	....	69
54	γ-Livetin	Egg yolk	sd	151,000	7.6	0.726	....	68
55	Lysozyme chloride	Chicken egg white	x	13,900	2.1	0.722	11.35(0.1)	5,78,134
56	Metakentrin	Sheep hypophysis	o; a	40,000	3.6	......	4.6(0.1)	60
57	Myosin	Rabbit muscle	sd; o	840,000-858,000	7.1	......	5.4(0.1-0.5)	25,88,89
58	Old yellow enzyme	Brewer's yeast	sd; e	105,000	5.8	0.753	5.22(0.02)	44,124
59	Ovalbumin	Chicken egg	sd	44,000	3.55	0.749	4.58(0.1)	49,61,114
60	Pepsin	Swine gastric mucosa	x	33,000-37,000	3.3	......	2.75-3.0	74,75,87
61	Phosvitin	Egg yolk	sd	30,900	3.14	0.545	....	41
62	Relaxin	Pregnant sow ovary	a; s	9,000	....	......	....	29
63	Ribonuclease	Cattle pancreas	x	13,400	1.85	0.709	7.8(0.055)	4,15,93
64	Ricin	Castor bean	sd	77,000-85,000	4.8-5.3	0.75[4]	5.2-5.5	43
65	Salmine	Salmon testes	a	7,000	<1	......	12	52,71,129
66	Serum albumin	Human blood	x	65,600	4.6	0.733	4.9	18,62,76
67	α_1-Serum globulin	Human blood	sv	200,000	5.0	0.841	....	76
68	β_1-Serum globulin	Human blood	sv	90,000	5.5	0.725	....	76
69	γ-Serum globulin	Human blood	sv	160,000	7.2	0.739	5.7(0.1)[17]	3,19,76
70	γ_1-Serum globulin antipneumococcus	Human blood	sd	190,000	7.4	0.745[4]	5.6(0.1)[18]	22,42
71	Tetanus toxin	*Clostridium tetani*	a; s	67,000	4.5	......	....	23
72	Thymus nucleohistone	Calf thymus	e; sd	2,000,000	31.0	0.658	....	16
73	Thyroglobulin	Swine thyroid	sd	700,000	19.2	0.72	4.58(0.02)	36
74	Tobacco mosaic virus	Tobacco leaves[5]	sd; sv; vd	33,000,000	185	0.72	3.49(0.02)	26,50
75	Trypsin	Cattle pancreas	a	20,700	2.5[19]	......	10.8(0.03 M)	9,20,40
76	Trypsin inhibitor	Cattle pancreas	o	6,000	....	......	....	48
77	Tuberculin protein	*Mycobacterium tuberculosis*	sd	32,000	1.9-4.9	......	4.3(0.03)	100
78	Tyrosinase	*Pseudomonas campestris*	sd	100,000	6.4	0.75[4]	<5	67
79	Urease	Jack bean	sd	480,000	18.6	0.73	5.0(0.012)[10]	5,110,112
80	Zein	Corn	sd	40,000	1.9	0.73[4]	....	135

/1/ Specific sedimentation velocity in units of 10^{-13}, under standard conditions of water at 20°C. /2/ Cubic centimeters increase in volume of solution per gram of protein dissolved. /3/ pH at which protein does not move in an electric field. /4/ Assumed value. /5/ Pathological. /9/ By cataphoresis. /10/ Based on solubility minimum. /13/ Several well-defined protein subunits, of which the commonest are the α chain (molecular weight = 15,128) and the β chain (molecular weight = 15,870). /14/ For horse blood. /15/ The A component molecular weight = 5,733, and sedimentation constant = 1.2 [28, 34, 35]. /16/ Two types, A and B, having same molecular weight and sedimentation constants. Isoelectric point for β-lactoglobulin B = 5.23. /17/ Depends on fraction employed. /18/ Hyperimmune horse blood. /19/ Value for diisopropylphosphate derivative.

continued

105. PROTEINS: PHYSICAL AND CHEMICAL CHARACTERISTICS

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106. AMINO ACIDS: PHYSICAL AND CHEMICAL CHARACTERISTICS

Solubility (columns E and F): a. = acid; ac. = acetic; acet. = acetone; al. = alcohol; alk. = alkali; aq. = aqueous; deliq. = deliquescent; dil. = dilute; e. = ethyl; eth. = ether; i. = insoluble; me. = methyl; s. = soluble; sl. = slightly; v. = very.

	Amino Acid	Chemical Formula	Molecular Weight	Melting Point[1] °C	Solubility[2]		Specific Rotation				Isoelectric Point pH
					Water 25°C	Other Solvents	Solvent	g/100 ml	Temp. °C	$[\alpha]_D$	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
1	L-Alanine	$C_3H_7O_2N$	89.09	297	16.51	sl. s. al.; i. acet., eth.	1.0 *N* HCl	5.79	15	+14.7	6.11[3]
2	β-Alanine	$C_3H_7O_2N$	89.09	196	v. s.	v. sl. s. al.; i. eth.	....	.....	...	0	6.90
3	L-2-Aminobutyric acid	$C_4H_9O_2N$	103.12	285	28	0.18, al.; i. eth.	20% HCl	.....	20	+14.1	5.98
4	L-Anserine	$C_{10}H_{16}O_3N_4$	240.26	238-239	s.	s. me. al.; sl. s. e. al.	H_2O	5.0	20	+12.2	8.27
5	L-Arginine	$C_6H_{14}O_2N_4$	174.20	238	v. s.	i. al., eth.	6.0 *N* HCl	1.65	23	+26.9	10.76
6	L-Asparagine	$C_4H_8O_3N_2$	132.12	236	2.46	s. dil. NH_4OH; v. sl. s. al.; i. eth.	3.4 *N* HCl	2.24	20	+34.3	5.41
7	L-Aspartic acid	$C_4H_7O_4N$	133.10	269-271	0.50	s. dil. HCl; v. sl. s. al.; i. eth.	6.0 *N* HCl	2.0	24	+24.6	2.98
8	L-Canaline	$C_4H_{10}O_3N_2$	134.14	214	s.	....	H_2O	1.6	21	-8.1	....
9	L-Canavanine	$C_5H_{12}O_3N_4$	176.18	184	s.	....	H_2O	3.2	20	+8.1	8.2
10	L-Carnosine	$C_9H_{14}O_3N_4$	226.23	246-250	s.	....	H_2O	2.0	20	+20.5	8.17
11	L-Citrulline	$C_6H_{13}O_3N_3$	175.19	222	v. sl. s.	i. al.	1.0 *N* HCl	2.0	27	+24.3	5.92
12	L-Cystathionine	$C_7H_{14}O_4N_2S$	222.26	270-312	......	s. HCl	1.0 *N* HCl	1.0	22	+23.7	....
13	L-Cysteic acid	$C_3H_7O_5NS$	169.17	260	s.	s. a., alk.; i. al.	H_2O	.....	...	+8.7	1.6
14	L-Cysteine	$C_3H_7O_2NS$	121.16	175-178	v. s.	s. a., alk.	H_2O	2.0	21	-10.1	5.07
15	L-Cystine	$C_6H_{12}O_4N_2S_2$	240.30	258-261	0.011	s. a.[4], NH_4OH; i. al., eth.	1.0 *N* HCl	1.0	24	-214.4	5.02
16	L-3,5-Dibromotyrosine	$C_9H_9O_3NBr_2$	338.99	245[5]	......	....	0.3 *N* HCl	.....	20	-2.4	4.30
17	L-3,4-Dihydroxyphenylalanine	$C_9H_{11}O_4N$	197.19	280	0.50	s. a., alk.; i. al., eth.	4% HCl	1.0	25	-12.0	....
18	L-3,5-Diiodotyrosine	$C_9H_9O_3NI_2$	432.99	194	0.62	....	1.1 *N* HCl	5.1	20	+2.9	4.29[3]
19	L-Djenkolic acid	$C_7H_{14}O_4N_2S_2$	254.33	300-350	0.10	....	1% HCl	2.0	26	-44.5	....
20	L-Ergothioneine	$C_9H_{15}O_2N_3S$	229.30	290	......	....	H_2O	5.0	21	+116.0	....
21	L-Ethionine	$C_6H_{13}O_2NS$	163.24	272-284	s.	....	0.2 *N* HCl	0.8	25	+23.5	....
22	L-Glutamic acid	$C_5H_9O_4N$	147.13	247	0.86	....	6.0 *N* HCl	1.0	22	+31.2	3.22[3]
23	L-Glutamine	$C_5H_{10}O_3N_2$	146.15	185-186	4.25	v. sl. s. al.; i. eth.	H_2O	.....	19	+8.0	5.65
24	Glycine	$C_2H_5O_2N$	75.07	233	24.99	0.043, 90% al.	....	.....	...	0	6.20
25	L-Histidine	$C_6H_9O_2N_3$	155.16	277	4.19	v. sl. s. al.; i. eth.	H_2O	1.1	25	-39.0	7.64
26	L-Homocysteine	$C_4H_9O_2NS$	135.19	232-233[3]	s.	....	....	.....	...	......	....
27	L-Homocystine	$C_8H_{16}O_4N_2S_2$	268.36	260-265[3]	v. sl. s.	....	1.0 *N* HCl	1.0	26	+77	5.53
28	L-δ-Hydroxylysine	$C_6H_{14}O_3N_2$	162.20	220	s.	s. a.; i. al.	6.0 *N* HCl	.....	25	+17.8	9.15
29	L-γ-Hydroxyproline	$C_5H_9O_3N$	131.13	238-241	36.11	v. sl. s. al.; i. eth.	H_2O	1.0	22	-75.2	5.82
30	L-Isoleucine	$C_6H_{13}O_2N$	131.18	283-284	4.12	0.09, al.; s. hot ac. a.; i. eth.	6.1 *N* HCl	5.1	20	+40.6[3]	6.04[3]

/1/ Most amino acids decompose when melting. /2/ Grams of amino acid soluble in 100 ml of solvent. /3/ Racemic mixture (DL). /4/ Mixture of acetonitrile and perchloric acid. /5/ Dihydrate.

continued

106. AMINO ACIDS: PHYSICAL AND CHEMICAL CHARACTERISTICS

	Amino Acid	Chemical Formula	Molecular Weight	Melting Point[1] °C	Solubility[2]		Specific Rotation				Isoelectric Point pH
					Water 25°C	Other Solvents	Solvent	g/100 ml	Temp. °C	$[\alpha]_D$	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
31	L-Lanthionine	$C_6H_{12}O_4N_2S$	208.24	245-295	i.	s. aq. NH_3, aq. HCl	2.4 *N* NaOH	5.0	22	+8.6	....
32	L-Leucine	$C_6H_{13}O_2N$	131.18	295	2.19	0.022, al.; s. ac. a.; i. eth.	6.0 *N* HCl	2.0	26	+15.1	6.04[3]
33	L-Lysine	$C_6H_{14}O_2N_2$	146.19	224	v. s.	v. sl. s. al.; i. eth.	6.0 *N* HCl	2.0	23	+25.9	9.47
34	L-Methionine	$C_5H_{11}O_2NS$	149.21	283	5.75	i. eth.	0.2 *N* HCl	0.8	25	+21.2	5.74[3]
35	L-Norleucine	$C_6H_{13}O_2N$	131.18	301	1.149[3]	0.017, al.[3]	6.0 *N* HCl	4.3	20	+21.3	6.08[3]
36	L-Norvaline	$C_5H_{11}O_2N$	117.15	291-292	10.7[6]	sl. s. al.; i. eth.	20% HCl	5	20	+22.8	6.04
37	D-Octapine	$C_9H_{18}O_4N_4$	246.27	229-230	s.	....	H_2O	.....	17	+20.9	5.51
38	L-Ornithine	$C_5H_{12}O_2N_2$	132.16	225	v. deliq.	v. s. al.; sl. s. eth.	H_2O	4.0	27	+16.5[5]	9.70
39	L-Phenylalanine	$C_9H_{11}O_2N$	165.19	283	2.96	sl. s. al.; i. eth.	H_2O	1.9	20	-35.1	5.91[3]
40	L-Proline	$C_5H_9O_2N$	115.13	220-222	162.3	1.55, al.; i. eth.	0.5 *N* HCl	0.6	20	-52.6	6.3
41	Sarcosine	$C_3H_7O_2N$	89.1	210	v. s.	sl. s. al.; i. eth.	....	.....	...	0	6.12
42	L-Serine	$C_3H_7O_3N$	105.09	228	5.023[3]	i. al., eth.	1.0 *N* HCl	9.3	25	+14.5	5.68[3]
43	L-Thiolhistidine	$C_6H_9O_2N_3S$	187.2	310[7]	s.	s. a.; i. al., organic solvents	1.0 *N* HCl	1.0	25	-9.5	5.16
44	L-Threonine	$C_4H_9O_3N$	119.12	229-230	20.1[3]	i. al., eth.	H_2O	1.0	26	-28.4	5.59
45	L-Thyroxine	$C_{15}H_{11}O_4NI_4$	776.88	235-236	0.001	i. al., eth.	0.13 *N* NaOH in 70% alcohol	3	...	-4.4	....
46	L-Tryptophan	$C_{11}H_{12}O_2N_2$	204.23	289	1.14	sl. s. al.; i. eth.	H_2O	1.0	20	-31.5	5.88
47	L-Tyrosine	$C_9H_{11}O_3N$	181.19	295	0.045	0.01, al.; s. alk.; i. eth., acet.	6.3 *N* HCl	4.4	20	-8.6	5.63
48	L-Valine	$C_5H_{11}O_2N$	117.15	293	8.85	0.019, al.[3]	6.0 *N* HCl	3.4	20	+28.8	6.00[3]

/1/ Most amino acids decompose when melting. /2/ Grams of amino acid soluble in 100 ml of solvent. /3/ Racemic mixture (DL). /5/ Dihydrochloride. /6/ At 5°C. /7/ Decomposes without melting.

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Abbreviations (columns H, I): a. = acid; abs. = absolute; ac. = acetic; acet. = acetone; al. = alcohol; alk. = alkali; uble; me. = methyl; pet. = petroleum; s. = soluble; sl. = slightly; v. = very; w. = water.

	Vitamin or Provitamin	Synonyms	Systematic Name	Chemical Formula	Physical State	Melting or Boiling Point °C
	(A)	(B)	(C)	(D)	(E)	(F)
	Vitamins					
1	Vitamin A_1	Retinol; antixerophthalmia factor	3,7-Dimethyl-9-(2,6,6-trimethyl-1-cyclohexen-1-yl)-2,4,6,8-nonatetraen-1-ol	$C_{20}H_{30}O$	Pale yellow prisms	62-64; distills at 120-125 at 5 x 10^{-3} mm
2	Vitamin A_2	Dehydroretinol		$C_{20}H_{28}O$	Yellow oil	
3	Vitamin A, neo-		2-*cis*-Vitamin A	$C_{20}H_{30}O$	Yellow needles	59-60
4	Vitamin A aldehyde	Retinene; retinal; axerophthal	All-*trans* form	$C_{20}H_{28}O$	Orange crystals	61-64
5	*p*-Aminobenzoic acid	PABA		$C_7H_7NO_2$	Monoclinic prisms from dilute alcohol	187.0-187.5
6	Ascorbic acid	Vitamin C; antiscorbutic factor	L-*threo*-2,3,4,5-6-Pentahydroxy-2-hexeno-γ-lactone	$C_6H_8O_6$	Crystals, plates or needles; monoclinic, colorless	190-192 (some decomposition)
7	Biotin	Vitamin H; coenzyme R; factor S, W, X; bios II G; antiegg-white injury factor	*cis*-Hexahydro-2-oxo-1H-thieno [3,4] imidazole-4-valeric acid	$C_{10}H_{16}N_2O_3S$	Fine long needles or white crystalline powder	232-233 (some decomposition)
8	Choline		(β-Hydroxyethyl)-trimethylammonium hydroxide	$C_5H_{15}NO_2$	Colorless, viscous, hygroscopic alkaline liquid	
9	Cobalamin	Cyanocobalamin (vitamin B_{12}); hydroxycobalamin (vitamin B_{12a}, B_{12b})	5,6-Dimethylbenzimidazolyl cyanocobamide	$C_{63}H_{90}CoN_{14}O_{14}P$	Hygroscopic, dark red needles; birefringent	Darkens at 210-220; not melted at 300
10	Vitamin D_2	Calciferol; ergocalciferol; activated ergosterol; antirachitic factor; oleovitamin D_2; viosterol	9,10-Secoergosta-5,7,10(19),22-tetraen-3-ol	$C_{28}H_{44}O$	Prisms from acetone	115-118; sublimes in very high vacuum without decomposition
11	Vitamin D_3	Activated 7-dehydrocholesterol; cholecalciferol; oleovitamin D_3	22,23-Dihydro-24-demethylcalciferol	$C_{27}H_{44}O$	Fine needles from dilute acetone	84-85
12	Vitamin E	α-Tocopherol, antisterility factor	5,7,8-Trimethyltocol	$C_{29}H_{50}O_2$	Slightly viscous, pale yellow oil	Boils at 200-220 at 0.1 mm
13		β-Tocopherol[5]	5,8-Dimethyltocol	$C_{28}H_{48}O_2$	Yellow oil	
14		γ-Tocopherol[5]	7,8-Dimethyltocol	$C_{28}H_{48}O_2$	Crystals	
15		σ-Tocopherol[5]	8-Methyltocol	$C_{27}H_{46}O_2$	Yellow oil	
16	Inositol	*meso*-Inositol; *i*-inositol; bios I	Hexahydroxycyclohexane	$C_6H_{12}O_6$	Efflorescent crystals (dihydrate)	218, dihydrate; 225-227, anhydrous
17	Vitamin K_1	Antihemorrhagic vitamin	2-Methyl-3-phytyl-1,4-naphthoquinone	$C_{31}H_{46}O_2$	Yellow, viscous oil	-20; decomposes above 100-120
18	Vitamin K_2		2-Methyl-3-difarnesyl-1,4-naphthoquinone	$C_{41}H_{56}O_2$	Yellow crystals	53.5-54.5
19	Nicotinic acid	Niacin; P.P. factor	Pyridine-3-carboxylic acid	$C_6H_5NO_2$	Colorless needles	236.5

/1/ Measurement based on sodium light of wavelength 589 mμ, unless otherwise indicated. /2/ $E^{1\%}_{1\,cm}$ = extinc-
α-tocopherol.

PHYSICAL AND CHEMICAL CHARACTERISTICS

bz. = benzene; chl. = chloroform; dil. = dilute; eth. = ether; glac. = glacial; gly. = glycerol; hex. = hexane; i. = insol-

Stability	Solubility g/100 ml	Specific Rotation[1]			Absorption Maxima		
		Solvent	Temp. °C	$[\alpha]_D$	Wavelength, mμ, $(E^{1\%}_{1\ cm})$[2]	Solvent	
(G)	(H)	(I)	(J)	(K)	(L)	(M)	
Vitamins							
Inactivated by ultraviolet; sensitive to air oxidation.	s. most organic solvents, fats, oils; i. w.	Inactive			325 (1,835)	Isopropanol	1
					288 (773), 352 (1,450)	Ethanol	2
					328 (1,686)	Ethanol	3
	s. most organic solvents, fats, oils; i. w.				373	Cyclohexane	4
Incompatible with ferric salts and oxidizing agents.	v.s. al., eth., glac. ac. a.; 0.5, w. (25°C); sl.s. bz.	Inactive			265 (1,090) 284 (1,020)	0.1 *N* NaOH At pH 3.75	5
Stable to air when dry; impure preparations and natural products oxidized by air and light.	3.5, al.; 2, abs. al.; 33, w.; 1, gly.	me. al. w.	23 25	+48 +20.5-21.5	243 (560) 266 (855)	0.1 *N* HPO_3 At pH 7	6
Stable to air, temperature; moderately acid and neutral solution stable several months; alkaline solution less stable.	0.080, al. (25°C); 0.022, w. (25°C); more s. hot w. or dil. alk.	0.1 *N* NaOH	21	+91			7
Dilute aqueous solution stable to boiling; decomposes in hot alkali.	v.s. al., w.; i. eth.						8
Heat-stable in aqueous solution; inactivated slowly by weak acid, alkali.	s. al.; 1.25, w.; i. acet., chl., eth.	dil. aqueous solution	23	-59±9[3]	278 (115), 361 (204), 550 (64)	Water	9
Crystals stable 9 montns in amber-evacuat d ampules at 4°C; propylene glycol solution stable to air for long periods.	6.95, acet. (7°C); s. most organic solvents; sl.s. vegetable oils; i. w.	acet. al. chl. eth.	20 20 20 20	+82.6 +103 +52 +91.2	264 (459)	Hexane	10
At least as stable as vitamin D_2.	s. most fat solvents; i. w.	acet.	20	+84.8	264 (450-490)	Hexane	11
Very stable to heat, acid; slowly oxidized by atmospheric O_2, rapidly by ferric and silver salts.	v.s. al., acet., chl., eth., fats, oils; i. w.	al. bz.	25 25	+0.32[4] -3.0[4]	294 (71-76)	Ethanol	12
		al.	25	+2.9[4]	295		13
		al.	25	+2.2[4]	295		14
		al.	25	+3.4[4]	298		15
Becomes anhydrous at 100°; decomposes at 250°.	14, w.; i. abs. al., eth.	Inactive					16
Stable to air, moisture; decomposes in sunlight; stable to dilute acid; labile to alkaline hydroxides.	s. acet., al., bz., chl., eth.; sl.s. me. al.; i. w.		20	-0.4	243 (410), 249 (425), 260 (395), 269 (395), 325 (75)	Hexane	17
					243 (320), 249 (329), 260 (305), 269 (305), 325 (58)	Hexane	18
Stable to air, light, pH; non-hygroscopic.	0.73, al. (25°C); 1.67, w. (25°C); i. eth.	Inactive			260.5 (432) 263 (260)	0.1 *N* HCl At pH 11	19

tion coefficients of 1% solutions of 1-cm thickness. /3/ D = 656 mμ. /4/ D = 546.1 mμ. /5/ Much less active than

continued

	Vitamin or Provitamin	Synonyms	Systematic Name	Chemical Formula	Physical State	Melting or Boiling Point °C
	(A)	(B)	(C)	(D)	(E)	(F)
	Vitamins					
20	Nicotinamide	Niacinamide	Pyridine-3-carboxamide	$C_6H_6N_2O$	Colorless needles	129-131
21	Pantothenic acid	Chick antidermatitis factor; factor II	D(*d*)-*N*-(α, γ-Dihydroxy-β, β-dimethylbutyryl)-β'-alanine	$C_9H_{17}NO_5$	Colorless, viscous oil	Unstable; calcium salt decomposes at 195-196
22	Pteroylglutamic acid	PGA; folic acid; folacin, vitamin M; *Lactobacillus casei* factor; vitamin B_c	*N*-[4-{[(2-Amino-4-hydroxy-6-pteridyl)-methyl]-amino}-benzoyl]-glutamic acid	$C_{19}H_{19}N_7O_6$	Yellowish-orange platelets	Darkens and chars from approximately 250
23	Pyridoxine[8]	Vitamin B_6-HCl; anti-acrodynia factor; adermine	5-Hydroxy-6-methyl-3, 4-pyridine dimethanol hydrochloride	$C_8H_{11}NO_3 \cdot HCl$	Colorless platelets	Decomposes: 205-212; sublimes: free base 160
24	Riboflavin	Vitamin B_2; vitamin G; lactoflavin; ovoflavin; hepatoflavin	6, 7-Dimethyl-9-(D-1'-ribityl)-isoalloxazine	$C_{17}H_{20}N_4O_6$	Yellow to orange-yellow polymorphic crystals	277-291 (some decomposition)
25	Thiamine	Vitamin B_1; aneurine; antineuritic factor	3-(4-Amino-2-methylpyrimidyl-5-methyl)-4-methyl-5-β-hydroxyethylthiazolium chloride hydrochloride[7]	$C_{12}H_{17}N_4OSCl \cdot HCl$	Monoclinic plates in rosette clusters, or white powder	246-250 decomposes
	Provitamins					
26	β-Carotene[9]	Provitamin A		$C_{40}H_{56}$	Red crystals	180 corrected
27	Ergosterol	Provitamin D_2	$\Delta^{5,7,22}$-Ergostatrien-3β-ol	$C_{28}H_{44}O$	Small white plates from alcohol	168
28	7-Dehydrocholesterol	Provitamin D_3	$\Delta^{5,7}$-Cholestadien-3β-ol	$C_{27}H_{44}O$	Crystals	150
29	22, 23-Dihydroergosterol	Provitamin D_4		$C_{28}H_{46}O$	Solvated needles from ethyl acetate and methyl alcohol	152-153
30	7-Dehydrositosterol	Provitamin D_5		$C_{29}H_{48}O$	Platelets from alcohol	144-145
31	7-Dehydrostigmasterol	Provitamin D		$C_{29}H_{46}O$	Crystals	154
32	*epi*-7-Dehydrocholesterol	Provitamin D_1		$C_{27}H_{44}O$	Crystals	124-126
33	Kitol	Dimer of vitamin A		$C_{40}H_{60}O_2$	Prisms from alcohol	88-90
34	Lumisterol	Provitamin D[10]		$C_{28}H_{44}O$	Needles from acetone methanol	118
35	Pantothenyl alcohol	Provitamin of pantothenic acid; pantothenylol; *N*-pantoyl-3-propanolamine	2, 4-Dihydroxy-*N*-(3-hydroxypropyl)-3, 3-dimethylbutyramide	$C_9H_{19}NO_4$	Colorless, viscous oil	Racemizes at boiling point
36	Tachysterol	Provitamin[10]		$C_{28}H_{44}O$		

/1/ Measurement based on sodium light of wavelength 589 mμ, unless otherwise indicated. /2/ $E^{1\%}_{1\,cm}$ = extinc-
amine, with different properties and biological activity. /7/ The mononitrate is a less hygroscopic form. /8/ Soret
ing vitamin A activity: α-carotene, γ-carotene, neo-β-carotene, and cryptoxanthin. /10/ Intermediates between

PHYSICAL AND CHEMICAL CHARACTERISTICS

Stability	Solubility g/100 ml	Specific Rotation[1] Solvent	Temp, °C	$[\alpha]_D$	Absorption Maxima Wavelength, mμ, $(E^{1\%}_{1\,cm})$[3]	Solvent	
(G)	(H)	(I)	(J)	(K)	(L)	(M)	
Vitamins							
Stable to air, light, pH; non-hygroscopic.	66.6, al.; 100, w.; sl.s. eth.	Inactive			260.5 (435) 262 (250)	0.1 *N* HCl At pH 11	20
Very hygroscopic; labile to acid, alkali, heat; calcium salt stable to air, light.	v.s. glac. ac. a., w.; sl.s. eth.; i. bz., chl.	 Ca salt	25 25	+37.5 +28.2			21
Very labile to heat in acid media; sunlight causes deterioration.	s. ac. a.; sl.s. me. al., w.; i. acet., bz., chl., eth.				256 (603), 282 (600), 365 (215)	At pH 11	22
Fairly stable to light, air. Acid solution stable; may be heated 120° for 30 minutes.	22, w.; 1.1, al., eth.; sl.s. acet.; i. eth.	Inactive			245 (306) 254 (179) 291 (420 310 (333) 325 (337)	0.1 *N* NaOH Phosphate buffer, pH 7 0.1 *N* HCl 0.1 *N* NaOH Phosphate buffer, pH 7	23
When dry, stable to diffused light; very labile to alkali solution, especially in light; stable to mineral acids in dark.	0.045, al. (27.5°C); 0.019, w. (40°C); i. acet., bz., chl., eth.	dil. alcoholic NaOH (50 mg in 2 ml)		-112 to -122	223 (800), 266 (870), 375 (288), 444 (310)	0.1 *N* HCl	24
Stable in acid solution and increasingly unstable as pH increases.	1, al.; 0.3, abs. al.; 5, gly.; 100, w.; i. bz., chl., eth., hex.				246 (410), 263S[8] (350)	0.1 *N* HCl	25
Provitamins							
Sensitive to O_2, autooxidation in light; stable to heat.	s. bz., CS_2, pet. eth.; sl.s. al., eth.; i. w.				450, 485, 520	CS_2	26
Destroyed by ultraviolet; decomposes oxidizing agents.	v.s. most fat solvents; i. w.	chl.		-130	280	Ether	27
	v.s. most fat solvents; i. w.	chl.		-113	280	Ether	28
	v.s. most fat solvents; i. w.	chl.		-109			29
Browns on contact with air.	v.s. most fat solvents; i. w.	chl.		-116	262, 271, 282, 293	Alcohol	30
	v.s. most fat solvents; i. w.	bz.		-113.1			31
	v.s. most fat solvents; i. w.	chl.		-70.5			32
	v.s. most fat solvents; i. w.	chl.		-1.35	286		33
	v.s. most fat solvents; i. w.	acet.		+192	265, 280		34
Labile to acid, alkali.	v.s. al., w.; sl.s. eth.	3% aqueous	20	+29.7			35
	v.s. most fat solvents; i. w.	bz.		-70	280		36

tion coefficients of 1% solutions of 1-cm thickness. /6/ The vitamin B_6 group also includes pyridoxal and pyridox-effect, i.e., the concentration varies with the temperature gradient within the solution. /9/ Other carotenoids hav-provitamin and vitamin.

continued

107. VITAMINS AND PROVITAMINS: PHYSICAL AND CHEMICAL CHARACTERISTICS

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108. VARIOUS CELLS AND CELL PARTS: CHEMICAL COMPOSITION

For information on additional species and tissues, consult reference 7. **Chemical Constituent** (column B): DNA = deoxyribonucleic acid; RNA = ribonucleic acid; N = nitrogen; P = phosphorus.

	Cell or Cell Part	Chemical Constituent	Value	Reference
	(A)	(B)	(C)	(D)
	Man			
1	Bone marrow, whole cell	DNA-P, μμg/cell	0.87	12
2		RNA-P, μμg/cell	0.69	
3	Brain, whole cell	DNA-P, μμg/cell	0.68	5
4		RNA-P, μμg/cell	2.63	
5	Leukocyte, whole cell	DNA-P, μμg/cell	0.73	12
6		RNA-P, μμg/cell	0.25	
7	Kidney, whole cell	DNA-P, μμg/cell	0.83	13
8		RNA-P, μμg/cell	1.10	
	Liver			
9	Whole cell	DNA-P, μμg/cell	1.0	13
10		RNA-P, μμg/cell	2.48	
11		Total N, μμg/cell	75.3	
12	Nucleus	Nucleoprotein, %	42-59	15
13		Acidic protein, %	35-51	
14		Other protein, "residual," %	4.7-7.5	
15	Sperm	DNA-P, μμg/sperm	0.31	13
16		RNA-P, μμg/sperm	0.24	
17	Spleen, whole cell	DNA-P, mg/g fresh tissue	0.77	11
18		RNA-P, mg/g fresh tissue	0.36	
	Cattle			
	Liver			
19	Whole cell	DNA-P, mg/g fresh tissue	0.34	11
20		RNA-P, mg/g fresh tissue	0.70	
21	Nucleus	Total nucleic acid, % dry wt	27.5-30.7	29
22		DNA, μμg/nucleus	6.4	6,40
23		RNA, % dry wt	0.9-1.9	29
24	Ribosome (calf)	RNA, %	40	32
25	Heart, nucleus	DNA, % dry wt	30.0	4
26		Total lipid, % dry wt	26.0	38
27		Phospholipid, % dry wt	15.7	38
28		Cholesterol, % dry wt	3.6	38
29		Fatty acid, % dry wt	6.5	38
	Pancreas			
30	Whole cell	DNA-P, mg/g fresh tissue	0.22	11
31		RNA-P, mg/g fresh tissue	1.77	
32	Nucleus	DNA, μμg/nucleus	6.6	6,40
	Sperm			
33	Whole cell	DNA, μμg/cell	2.82-3.40	6,31
34	Head	Total nucleic acid, % dry wt	48.0	10
35		DNA, μμg/head	3.3	6,40
36		Basic protein, % dry wt	28.7	10
37		Acidic protein, "lipo-," % dry wt	19.6	10
38	Spleen, nucleus	Total nucleic acid, % dry wt	32.6-33.6	29
39		DNA, μμg/nucleus	6.8	6,40
40		RNA, % dry wt	0.7-1.1	29
	Thymus			
41	Whole cell (calf)	DNA-P, mg/g fresh tissue	2.24-2.50	11
42		RNA-P, mg/g fresh tissue	0.80-1.00	
43	Nucleus	Total nucleic acid, %total N	31.0	30
44		Basic protein, % total N	35.0	30
45		Acidic protein, % total N	14.0	30
46		DNA, μμg/nucleus	6.4	6,40
	Dog			
	Liver			
47	Whole cell	Total lipid, % dry wt	17.2	44
48		Phospholipid, % dry wt	9.2	
49		Cholesterol, % dry wt	1.07	
50		Neutral fat, % dry wt	6.9	
51	Nucleus	DNA, μμg/nucleus	5.3	42
52		Total lipid, % dry wt	16.5	44
53		Phospholipid, % dry wt	10.7	44
54		Cholesterol, % dry wt	1.2	44
55		Fatty acid, % dry wt	4.6	44
56	Sperm, head	Total nucleic acid, % dry wt	55.3	10
57		Basic protein, % dry wt	25.0	
58		Acidic protein, "lipo-," % dry wt	17.0	
	Guinea Pig			
	Liver			
59	Whole cell	DNA-P, mg/g fresh tissue	0.42	34
60		RNA-P, mg/g fresh tissue	0.97	34
61		Total protein, % dry wt	15.0	26

continued

	Cell or Cell Part	Chemical Constituent	Value	Reference
	(A)	(B)	(C)	(D)
	Guinea Pig			
62	Liver Mitochondria	Total N, % dry wt of fraction[1]	10.0-12.0	8
63		Total lipid, % dry wt of fraction[1]	25.0	
64		Phospholipid, % dry wt of fraction[1]	16.0	
65	Microsome	Total N, % dry wt of fraction[2]	9.15	8
66		Total lipid, % dry wt of fraction[2]	40.0-51.0	8,27
67		Phospholipid, % dry wt of fraction[2]	28.0-29.0	8,27
68		Phospholipid, % total lipid	58	27
	Mouse			
69	Liver Whole cell	DNA, mg/g fresh tissue	2.85	3
70		RNA, mg/g fresh tissue	9.0	3
71		DNA-P, mg/g fresh tissue	0.232	25
72		RNA-P, mg/g fresh tissue	0.927	25
73		Total protein, mg/g fresh tissue	126.3	3
74		Phospholipid, mg/g fresh tissue	30.1	3
75	Nucleus	DNA, %	27.0	3
76		RNA, %	3.4	
77		Nucleoprotein, %	66.0	
78		Phospholipid, %	3.4	
79	Mitochondria	DNA, % total nucleic acid	5.6[3]	36
80		RNA, % total nucleic acid	16.8	36
81		RNA, % dry wt of fraction[1]	3.7	2
82		Total N, %	23.5	35
83		Total N, % dry wt of fraction[1]	12.1	2
84		Total lipid, % dry wt of fraction[1]	27.4	2
85		Phospholipid, % total lipid	56.6	2
86		Cholesterol[4], % total lipid	12.6	2
87		Neutral fat, % total lipid	30.8	2
88	Microsome	DNA, % total nucleic acid	14.2[3]	36
89		RNA, % total nucleic acid	52.4	36
90		RNA, % dry wt of fraction[2]	9.1	2
91		Total N, %	23.1	35
92		Total N, % dry wt of fraction[2]	10.3	2
93		Total lipid, % dry wt of fraction[2]	35.1	2,26
94		Phospholipid, % total lipid	62.7	2,26
95		Cholesterol[4], % total lipid	14.5	26
96		Neutral fat, % total lipid	22.8	26
	Rat			
97	Bone marrow Whole cell	DNA-P, mg/g fresh tissue	1.53	39
98		RNA-P, mg/g fresh tissue	0.87	
99	Nucleus	DNA, μμg/nucleus	6.90	39
100	Heart Whole cell	DNA-P, mg/g fresh tissue	0.306	39
101		RNA-P, mg/g fresh tissue	0.314	
102	Heart Nucleus	DNA, μμg/nucleus	6.46	39
103	Kidney Whole cell	DNA-P, mg/g fresh tissue	0.267	39
104		RNA-P, mg/g fresh tissue	0.657	
105	Nucleus	DNA, μμg/nucleus	6.72	39
106	Liver Whole cell	DNA, mg/g fresh tissue	1.92	33
107		RNA, mg/g fresh tissue	5.88	33
108		DNA-P, mg/g fresh tissue	0.21-0.25	11
109		RNA-P, mg/g fresh tissue	0.77-1.10	11
110		Total protein, mg/g fresh tissue	129.0	33
111		Total lipid, % dry wt	15.2	44
112		Phospholipid, % dry wt	8.3	44
113		Cholesterol, % dry wt	2.4	44
114		Neutral fat, % dry wt	4.1	44
115	Nucleus	Total nucleic acid, % dry wt	11.4-27.5	20,29
116		DNA, mg/g fresh tissue	1.84	33
117		DNA, % dry wt	4.4-30.0	20,43
118		RNA, mg/g fresh tissue	0.64	33
119		RNA, % dry wt	2.9-7.6	20,29
120		Nucleoprotein, mg/g fresh tissue	20.0	33
121		Total lipid, % dry wt	10.5-18.1	17,43,44
122		Total lipid, %	3.2-10.0	18
123	Mitochondria	DNA, % total nucleic acid	11.7[3]	23
124		RNA, % total nucleic acid	19.0-46.0	22,23
125		RNA-P, μg/mg N	11.0	37
126		Total N, %	23.0-38.6	22,23,37
127		Total protein, %	30.0-33.0	37
128		Total protein, mg/g fresh tissue	35.0-40.0	33
129		Total lipid, % dry wt of fraction[1]	25.0-30.0	37
130		Phospholipid, % total lipid	66.0	37
131	Microsome	RNA, % total nucleic acid	50.0	37
132		Total N, %	18.0-20.0	37
133		Total protein, mg/g fresh tissue	19.0-21.0	33
134		Total lipid, % dry wt of fraction[2]	40.0	37
135	Lung Whole cell	DNA-P, mg/g fresh tissue	0.921	39
136		RNA-P, mg/g fresh tissue	0.520	
137	Nucleus	DNA, μμg/nucleus	6.71	39
138	Spleen Whole cell	DNA-P, mg/g fresh tissue	1.40	39
139		RNA-P, mg/g fresh tissue	0.499	
140	Nucleus	DNA, μμg/nucleus	6.52	39
	Rabbit			
141	Kidney Whole cell	DNA-P, mg/g fresh tissue	0.125	28
142		RNA-P, mg/g fresh tissue	0.167	
143	Nucleus	Total nucleic acid, % dry wt	26.0	29
144		RNA, % dry wt	1.2	
145	Liver Whole cell	DNA-P, mg/g fresh tissue	0.16-0.29	11
146		RNA-P, mg/g fresh tissue	0.44-0.76	

/1/ Large granule fraction obtained by differential centrifugation of liver cytoplasm extract. /2/ Small granule fraction obtained by differential centrifugation of liver cytoplasm extract. /3/ Contamination with nuclear material cannot be excluded. /4/ Unsaponifiable.

continued

108. VARIOUS CELLS AND CELL PARTS: CHEMICAL COMPOSITION

	Cell or Cell Part	Chemical Constituent	Value	Reference
	(A)	(B)	(C)	(D)
	Rabbit			
147	Liver Nucleus	Total nucleic acid, % dry wt	26.2	29
148		RNA, % dry wt	2.0	
149	Mitochondria	Nucleic acid P, µg/mg total N	70.0	1
150		Total N, % dry wt of fraction[1]	10.5	
151		Total lipid, % dry wt of fraction[1]	29.6	
152		Phospholipid, % dry wt of fraction[1]	17.5	
153	Microsome	Nucleic acid P, µg/mg total N	80.0	1
154		Total N, % dry wt of fraction[2]	9.0	
155		Total lipid, % dry wt of fraction[2]	43.4	
156		Phospholipid, % dry wt of fraction[2]	31.2	
157	Reticulocyte, ribosome	RNA, %	50	16
	Fowl			
158	Erythrocytes, nucleus	Total nucleic acid, % dry wt	33.9-38.1	29
159		DNA, µµg/nucleus	2.34-2.49	14,31
160		DNA, %	45.0	19
161		RNA, % dry wt	0.7-2.5	29
162		Nucleoprotein, %	50.0-60.0	24
163		Acidic protein, %	33-40	24
164	Liver Whole cell	DNA-P, mg/g fresh tissue	0.31-0.41	9
165		RNA-P, mg/g fresh tissue	0.76-0.84	
166	Nucleus	Total nucleic acid, % dry wt	29.4-31.2	29
167		DNA, µµg/nucleus	2.39-2.54	14,31
168		RNA, % dry wt	2.0-2.2	29
169	Sperm, nucleus	DNA, µµg/nucleus	1.26	31
170	Thymus, nucleus	Total nucleic acid, % dry wt	32.0-36.3	29
171		RNA, % dry wt	1.3-1.4	
	Fish			
172	Cod sperm, head	Total nucleic acid, % dry wt	30.3	29
173		RNA, % dry wt	0.3	
174	Herring sperm, head	Total nucleic acid, % dry wt	38.8-59.0	29
175		RNA, % dry wt	0-0.2	
176	Salmon sperm, head	Total nucleic acid, % dry wt	60.8	29
177		RNA, % dry wt	0.1	
	Sea Urchin[5]			
178	Ovum	DNA, µµg/cell	28.0	21
179		DNA, % dry wt	0.01	
180	Sperm	DNA, µµg/cell	1.0	21
181		DNA, % dry wt	15.0	
	Bacteria			
182	*Bacillus anthracis*	Total nucleic acid, % dry wt	4.35	41
183		DNA, % dry wt	1.15	
184		RNA, % dry wt	3.20	
185		Total N, % dry wt	10.0	
186		Total protein, % dry wt	58.1	
187	*Escherichia coli*	Total nucleic acid, % dry wt	12.84	41
188		DNA, % dry wt	3.72	
189		RNA, % dry wt	9.12	
190		Total N, % dry wt	14.61	
191		Total protein, % dry wt	78.5	
192	*Salmonella typhosa*	Total nucleic acid, % dry wt	13.12	41
193		DNA, % dry wt	4.40	
194		RNA, % dry wt	8.72	
195		Total N, % dry wt	14.40	
196		Total protein, % dry wt	76.8	
197	*Staphylococcus* (strain 72)	Total nucleic acid, % dry wt	11.57	41
198		DNA, % dry wt	2.82	
199		RNA, % dry wt	8.75	
200		Total N, % dry wt	13.95	
201		Total protein, % dry wt	75.5	

/1/ Large granule fraction obtained by differential centrifugation of liver cytoplasm extract. /2/ Small granule fraction obtained by differential centrifugation of liver cytoplasm extract. /5/ *Paracentrotus lividus.*

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109. ANIMAL TISSUES AND ORGANS: WATER CONTENT

Values are for adult animals, unless otherwise indicated. Values in parentheses are ranges, estimate "c" unless otherwise indicated (cf. Introduction).

	Tissue or Organ	% water	Reference
	(A)	(B)	(C)
	Man		
	Nervous tissue		
1	Whole brain	77(76-78)	39
2	White matter	70(68-73)	39
3	Gray matter	84(82-85)	39
4	Spinal cord	71(63-75)	39
5	Peripheral nerve	66(62-68)	39
6	Eye lens	67.6	57
	Dental tissue		
7	Whole teeth	9.2(4.0-14.3)	13
8	Enamel[1]	2.8	6
9	Dentin[1]	11.1	6
	Alimentary tract		
10	Cardiac stomach	73.4	50
11	Pyloric stomach	68.6	50
12	Small intestine	71.0(60.2-81.8)	50
13	Large intestine	72.7	50
14	Liver	75.0(72.9-77.3)	50
15	Pancreas	74.8	46
16	Spleen	78.7(76.5-81.1)	50
17	Lung	81.3(79.5-82.7)	50
	Cardiac tissue		
18	Whole heart	77.6(71.2-80.3)	50
19	Left ventricle	79.2	11
20	Right ventricle	80.7	11
	Cardiac tissue		
21	Right atrium	81.2	11
22	Septum	79.2	11
23	Kidney	78.4(77.7-79.0)	50
	Reproductive tissue		
24	Testis	84.0	50
25	Prostate gland	82.5	50
26	Ovary[2]	80.5	44
27	Uterus	79.9	50
28	Muscle	76.0	10
29	Bone	43.9	60
30	Skin[2]	71.8(67.8-75.8)[b]	23
31	Hair	4.1(4.0-4.2)	4
	Cat		
	Nervous tissue		
32	Whole brain	72.2	41
33	White matter	69	30
34	Gray matter	82	30
35	Spinal cord	67.7	42
36	Sciatic nerve	(66.2-68.9)	35
37	Eye lens[3]	74.5	7
38	Liver	70.7(68.7-72.7)[b]	65
	Cardiac tissue		
39	Whole heart	78.7	56
40	Left ventricle	77.7	61

/1/ Deciduous teeth. /2/ Fat-free basis. /3/ Young animal.

continued

109. ANIMAL TISSUES AND ORGANS: WATER CONTENT

	Tissue or Organ	% Water	Reference
	(A)	(B)	(C)
	Cat		
	Cardiac tissue		
41	Right ventricle	77.4	61
42	Muscle	77.0(76.4-77.6)[b]	65
	Cattle		
	Nervous tissue		
43	Whole brain	77.9	51
44	White matter	68.0(67.5-68.5)[b]	16
45	Gray matter	77.5(74.7-80.1)[b]	16
46	Spinal cord	(64-65)	39
47	Obturator nerve	54.7(52.5-56.9)[b]	16
	Eye		
48	Cornea	77.9(77.3-78.5)[b]	17
49	Lens	64.3	7
50	Retina	85.9	12
51	Liver	69.0	20
52	Lung	80.0	51
	Cardiac tissue		
53	Whole heart	70.0	51
54	Left ventricle	79.0(77.8-80.2)[b]	16
55	Right ventricle	77.5(77.2-77.8)[b]	16
56	Left atrium	79.7(79.4-80.0)[b]	16
57	Right atrium	81.6(80.9-82.3)[b]	16
58	Tricuspid valve	86.1(85.0-87.2)[b]	16
59	Kidney	74.9	51
60	Testis	86.0	55
61	Muscle	70.0	51
	Dog		
	Nervous tissue		
62	Whole brain	(74.5-76.1)	22
63	White matter	69(64-71)	28,39
64	Gray matter	80(79-82)	28,39
65	Spinal cord	69(67-70)	39
66	Peripheral nerve	66(57-71)	39
67	Intestine	75.7	38
68	Liver	74.6	38
69	Pancreas	72.1	38
70	Spleen	77.4	38
71	Lung	78.6(77.1-80.1)	62
	Cardiac tissue		
72	Whole heart	78.3(76.6-79.9)	63
73	Left ventricle	77.4	59
74	Right ventricle	77.1	59
75	Left atrium	74.9	59
76	Right atrium	74.6	59
77	Kidney[2]	80.2(79.1-81.3)[b]	21
78	Testis	87.3(78.5-96.1)[b]	33
79	Muscle	76.5	32
	Bone		
80	Humerus	52.5(49.6-57.6)	9
81	Femur	52.1(49.5-56.5)	9
82	Tibia	48.4(45.5-52.1)	9
83	Skin	63.7(44.2-82.3)	18
	Guinea Pig		
	Nervous tissue		
84	Whole brain	78.7	41
85	Spinal cord	70.5	42
86	Liver	71.8(70.3-75.4)	45
87	Lung	78.5(77.0-79.3)	52
88	Heart	76.1	51
89	Muscle	74.9	51
	Horse		
	Nervous tissue		
90	Whole brain	71	25
91	Peripheral nerve	69	2
92	Eye lens	67.5	7
93	Heart	63.0	5
	Rabbit		
	Nervous tissue		
94	Whole brain	(78-85)	27,41
95	White matter	70(65-76)	39
96	Gray matter	81.6(81.1-82.3)	3,39
97	Spinal cord	(66.8-70.5)	42,44
98	Peripheral nerve	62(59-66)	39
	Alimentary tract		
99	Stomach	(77.0-80.2)	24,44
100	Small intestine	80.6	44
101	Duodenum	80.0	24
102	Cecum	83.3	24
103	Ileum	82.0	24
104	Colon	74.8	44
105	Liver	73.0(70.0-76.0)	24
106	Spleen	78.0	24
107	Lung	(80.1-82.0)	24,44
	Cardiac tissue		
108	Whole heart	78.2	44
109	Left ventricle	77.9	19
110	Right ventricle	78.0	19
111	Kidney	(74.0-78.6)	24,44
	Reproductive tissue		
112	Testis	(68.0-85.0)	24,44
113	Ovary	(72.0-77.0)	24,44
114	Muscle	77.0	24
115	Bone	(39.2-58.1)	8
116	Skin	(54.0-67.8)	24,44
117	Hair	(10.0-13.0)	24
	Rat		
	Nervous tissue		
118	Whole brain	78.7(78.0-79.5)	44
119	White matter	79.4(78.4-80.4)	14
120	Gray matter	(81-82)	53
	Alimentary tract		
121	Stomach	73.7(71.9-74.8)	44
122	Small intestine	67.2	44
123	Large intestine	77.1	44
124	Liver	70.7(70.2-71.3)	44
125	Spleen	77.5(77.1-77.9)	44
126	Lung	81.2(79.1-85.3)	44
127	Heart	76.6(76.0-77.2)	37
128	Kidney	76.8(76.4-77.3)	44
	Reproductive tissue		
129	Testis[2]	87.3(87.1-88.3)	44
130	Ovary	73.9(72.7-75.1)	29
131	Muscle	76.1	44
132	Bone	34.0	8
133	Skin	(57.4-61.9)	64
	Sheep		
	Nervous tissue		
134	White matter	74.2	15
135	Gray matter	84.2	15
136	Liver[3]	67.1	51
137	Muscle	(52-64)	54

/2/ Fat-free basis. /3/ Young animal.

continued

109. ANIMAL TISSUES AND ORGANS: WATER CONTENT

	Tissue or Organ	% Water	Reference
	(A)	(B)	(C)
	Sheep		
138	Bone	17.0(12.3-22.0)	66
139	Wool	17.0(9.0-28.0)	47
	Swine		
140	Brain	77.0	25
141	Tooth pulp	89.8	49
142	Liver	78.0	58
143	Spleen	81.5	58
144	Muscle	65.3	31
145	Hair	11.4	43
	Chicken		
146	Brain	78	36
147	Feathers	9.1	43
	Pigeon		
148	Brain	(78.4-80.0)	34
149	Muscle	74.0	51
	Frog		
	Nervous tissue		
150	Whole brain	84	1
151	Peripheral nerve	85	26
152	Muscle	(78.9-81.6)	48
	Carp		
153	Brain	74	1
154	Eye lens	52	7
	Eel		
155	Liver	77.9	40
156	Muscle	57.1(53.8-59.1)	40
157	Skin	66.5	40

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109. ANIMAL TISSUES AND ORGANS: WATER CONTENT

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110. CELL SAP: CHEMICAL COMPOSITION

	Species (Common Name)	Plant Part	Growth Stage	Constituent	Value mg/100 g	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
1	*Avena sativa* (common oat)	Stem	Mature	NO_3-N	41	3
2	*Beta saccharifera* (sugar beet)	Leaf	Mature	Mg	80-200	7
3			Mature	P	10.5-251.0	7
4			Mature	K	97-516	7
5			44-79 da	NO_3-N	3-52	5
6		Stem	Mature	Mg	70-130	7
7				P	4.5-24.2	
8				K	34.0-41.4	
9	*Daucus carota* (carrot)	Root	2-3 mo	NO_3-N	3.1-31.8	5
10				P	0.04-1.00	
11	*Fagopyrum esculentum* (buckwheat)	Leaf	....	P	22-105	8
12		Stem	....	P	24-145	8
13		Shoot	....	NO_3-N	12.6-17.2	5
14	*Glycine soja* (soybean)	Entire plant	Fruiting	NO_3-N	2.4-3.6	11
15				P	2.6-9.0	
16				K	96-885	
17	*Hordeum vulgare* (barley)	Leaf	Mature	NO_3-N	20	3
18				P	6.4-55.6	7
19				K	310-860	7
20		Stem	Mature	NO_3-N	23	3
21				P	8.9-77.7	7
22				K	260-800	7
23		Entire plant	36 da	P	10	7
24				K	250	
25	*Lactuca sativa* (lettuce)	Leaf	Mature	NO_3-N	6-45	5
26	*Lycopersicon esculentum* (tomato)	Petiole	Fruiting	NO_3-N	6.9	6
27			....	P	30	
28		Stem	Immature	Ca	18	6
29	*Lycopersicon esculentum* (tomato)	Stem	Immature	NO_3-N	5.8-11.5	6
30			Immature	P	12.5-20.0	
31			Immature	K	200-300	
32			....	Mg	6-41	
33		Shoot	Immature	P	9.7-19.2	1
34	*Phaseolus vulgaris* (kidney bean)	Leaf	Mature	Ca	515-690	7
35				Mg	42-109	
36				P	3.5-17.7	
37				K	28-200	
38		Stem	Mature	Ca	137-283	7
39				Mg	76-105	
40	*Solanum tuberosum* (potato)	Lower stem	Mature	Ca	100	2
41			Mature	P	6	2
42			Mature	K	254-622	5
43			....	NO_3-N	16.1-18.4	1
44	*Triticum aestivum* (wheat)	Shoot	Immature	P	35-81	7
45			Mature	Ca	68-106	
46			Mature	NO_3-N	1.4-5.8	
47			....	Mg	27-107	
48		Entire plant	Immature	Ca	43	4
49				Mg	39	
50				NO_3-N	2.8	
51				P	80	
52				K	411	
53	*Vigna sinensis* (cowpea)	Petiole	....	Mg	19-42	1
54				NO_3-N	2.2-22.0	
55				P	1.2-4.4	
56				K	250-415	
57	*Zea mays* (corn)	Stem	....	Ca	4.7-11.6	10
58		Lower stem	Mature	NO_3-N	8-41	4
59				P	2.7-3.8	5
60				K	166	9
61		Entire plant	Mature	NO_3-N	0.5-25.0	4
62			Mature	P	1.6-12.2	9
63			....	K	390-650	9

Contributors: (a) Giddens, Joel, (b) Samuels, George

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continued

110. CELL SAP: CHEMICAL COMPOSITION

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111. PLANT TISSUES AND ORGANS: MINERAL COMPOSITION

Plant Part (column B): veg. = plants in vegetative condition; fl. = plants flowering; fr. = plants fruiting; yg. = young; e. = early; im. = immature; un. = unripe.

Part I. MAJOR ELEMENTS

Values are g/100 g of dry weight.

	Species (Common Name) (A)	Plant Part (B)	Potassium (C)	Phosphorus (D)	Calcium (E)	Magnesium (F)	Sulfur (G)	Reference (H)
	Monocotyledoneae							
1	*Allium cepa* (garden onion)	Shoots	2.59	0.187	2.59	0.262	0.177	11
2		Bulbs	1.03-1.92	0.17-0.74	0.260-0.863	0.11-0.16	0.120-0.600	7,12
3	*Asparagus officinalis* (garden asparagus)	Shoots	1.45-3.45	0.140-0.783	0.249-1.358	0.097-0.190	0.132-0.260	11,12
4		Shoots, yg.	2.665	0.529	0.329	0.048	0.176	12
5		Roots	2.914	0.105	1.043	0.078	0.172	12
6		Fruits	0.155-1.669	0.293-0.382	0.088-0.114	0.036-0.129	0.101-0.172	12
7	*Avena sativa* (common oat)	Shoots, veg.	2.780-2.880	0.244-0.365	0.380-0.534	0.150-0.218	0.136-0.170	10,11
8		Shoots, fl.	2.01-2.17	0.212-0.480	0.314-0.730	0.133-0.330	0.067-0.570	9-11
9		Shoots, fr.	0.78-2.20	0.16-0.40	0.21-0.51	0.13-0.41	0.07-0.28	7,72
10		Straw	0.59-3.52	0.02-0.36	0.15-0.67	0.06-0.54	0.08-0.51	7,12
11		Grain	0.280-1.086	0.150-0.955	0.019-0.190	0.060-0.356	0.020-0.294	7,12,35,62
12	*Elodea canadensis* (Canada waterweed)	Shoots	1.48-3.01	0.275-0.744	2.91-8.23	0.468-1.168	0.147-0.968	11
13	*Hordeum vulgare* (barley)	Shoots	3.88	0.347	0.677	0.250	0.192	11
14		Shoots, veg.	2.44	0.327	0.357	0.119	0.097	11
15		Shoots, fl.	1.37	0.291	0.267	0.118	0.076	11
16		Straw	1.08-1.96	0.04-0.56	0.15-0.60	0.040-0.287	0.018-0.230	7,12
17		Grain	0.270-0.923	0.150-0.620	0.011-0.150	0.018-0.273	0.019-0.366	7,12,35,62
18	*Oryza sativa* (rice)	Straw	0.930-1.640	0.066-0.130	0.193-0.300	0.060-0.110	0.100-0.138	1,12,49,75,82
19		Roots	0.755	0.079	0.307	0.121	....	12
20		Grain	0.243-0.480	0.190-0.430	0.050-0.138	0.092-0.170	0.001-0.138	1,7,12,19,75
21	*Phleum pratense* (timothy)	Shoots	0.79-3.84	0.080-0.600	0.040-1.200	0.030-0.380	0.072-0.320	3,7,11
22		Shoots, fl.	0.92-2.32	0.17-0.41	0.15-0.44	0.09-0.17	0.02-0.27	7,8
23		Shoots, fr.	1.58	0.17	0.16	0.07	0.16	7
24		Grain	0.458	0.347	0.162	0.122	0.026	12
25	*Phoenix dactylifera* (date palm)	Pinnae	0.232-1.640	0.060-0.186	0.295-1.118	0.051-0.244	....	37,70
26	*Poa pratensis* (Kentucky bluegrass)	Shoots	1.35-4.33	0.189-0.952	0.130-1.200	0.089-0.230	0.055-0.656	3,11,17,27,59, 62,78,79
27		Shoots, veg.	....	0.193-0.611	0.302-0.871	....	....	8,16,69
28		Shoots, fl.	1.41-2.85	0.164-0.403	0.130-0.424	0.11	....	7,27
29		Shoots, fr.	1.52-2.07	0.200-0.299	0.189-0.300	0.115	0.18	33,72
30		Grain	0.670	0.850	0.315	0.197	0.202	59
31	*Triticum aestivum* (wheat)	Shoots	2.88	0.249	0.368	0.174	0.120	11
32		Shoots, veg.	2.81	0.315	0.845	0.085	0.111	11
33		Shoots, fl.	1.61	0.233	0.194	0.112	0.052	11
34		Straw	0.26-1.54	0.03-0.17	0.08-0.43	0.03-0.22	0.07-0.30	7,28
35		Grain	0.237-0.971	0.150-0.540	0.005-0.296	0.090-0.290	0.003-0.290	7,12,28,35,62, 80
36	*Zea mays* (corn)	Leaves	0.24-1.57	0.052-0.256	0.11-0.91	0.17-0.29	0.23-0.25	12,32,53,94
37		Stems	0.260-2.433	0.026-0.202	0.140-0.629	0.140-0.290	0.05-0.17	12,32,53,94
38		Shoots, fl.	1.669-1.790	0.136-0.550	0.592-0.681	0.230-0.392	0.075-0.370	11,12

continued

III. PLANT TISSUES AND ORGANS: MINERAL COMPOSITION

Part I. MAJOR ELEMENTS

	Species (Common Name)	Plant Part	Potassium	Phosphorus	Calcium	Magnesium	Sulfur	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
				Monocotyledoneae				
39	*Zea mays* (corn)	Shoots, fr.	0.26-1.89	0.04-0.42	0.10-0.84	0.08-0.51	0.08-0.31	7,11,28,95
40		Roots	0.270-1.277	0.030-0.141	0.129-0.720	0.094-0.180	0.033-0.280	12,53
41		Flowers, ♂	1.264	0.146	0.569	0.268	....	12
42		Flowers, ♀	1.482	0.146	0.630	0.343	....	12
43		Kernels	0.22-0.92	0.23-0.80	0.006-0.060	0.09-0.27	0.004-0.300	7,12,28,53,62
44		Cob	0.46	0.094	0.022	0.11	0.021	53
				Dicotyledoneae				
45	*Acer saccharum* (sugar maple)	Leaves	0.95-1.58	0.24-0.46	0.57-2.42	0.24-0.35	0.01-0.24	61
46	*Alnus glutinosa* (European alder)	Pollen	1.708	0.532	0.264	....	....	30
47		Fruits	0.412	0.105	0.358	0.121	0.027	12
48	*Beta vulgaris* (common beet)	Leaves	1.68-6.45	0.089-0.436	0.78-3.12	0.17-1.74	0.345-0.845	7,11,12,46,62
49		Shoots	1.01-7.64	0.08-0.38	0.39-2.83	0.26-1.07	0.31-0.61	7
50		Crowns	....	0.091-0.169	0.81-1.50	0.24-0.65	....	7,46
51		Roots	0.370-4.539	0.035-0.620	0.09-2.83	0.013-0.498	0.03-0.23	7,12,46,62,72
52		Pollen	1.141	0.346	....	....	0.119	12
53		Fruits	0.878-1.530	0.284-0.402	0.631-1.062	0.516-0.645	0.095-0.168	12
54		Fruit coats	2.60	0.173	1.74	1.644	0.278	12
55		Seeds	0.952	0.441	0.948	0.477	0.101	12
56	*Betula populifolia* (gray birch)	Bark	0.159	0.052	0.485	0.072	0.003	12
57		Wood	0.066	0.021	0.069	0.033	0.002	12
58		Fruits	0.944	0.200	0.715	0.233	0.081	12
59	*Carya illinoensis* (pecan)	Leaves	0.337-0.924	0.097-0.148	1.129-1.583	0.376-0.403	....	40
60	*Catalpa speciosa* (northern catalpa)	Leaves	1.31-2.47	0.30-0.58	1.17-2.26	0.34-0.51	0.22-0.48	61
61	*Chrysanthemum segetum* (corn chrysanthemum)	Shoots	1.596	0.388	0.588	0.390	0.212	11
62		Shoots, fl.	2.00-5.37	0.279-0.682	1.110-1.133	0.226-0.465	0.055-0.266	11
63	*Cinchona ledgeriana* (ledger-bark cinchona)	Leaves	0.82-1.21	0.20-0.49	0.43-0.70	0.21-0.29	....	[illegible]
64	*Citrus limon* (lemon)	Leaves	1.55-7.43	....	3.621-4.365	0.397-0.619	....	24,38
65		Bark	0.142-0.750	....	2.088-2.864	0.151-0.460	....	38
66		Root bark	0.159-0.578	....	1.878-2.671	0.155-0.303	....	38
67		Small roots	0.142-0.806	....	0.613-0.883	0.325-0.580	....	38
68		Fruits	1.08-1.46	0.16-0.22	0.39-0.92	0.09-0.14	0.04-0.05	7
69		Fruit rinds	0.388-0.830	....	0.826-1.047	0.132-0.164	....	38
70		Fruit pulp	0.560-2.041	....	0.260-0.348	0.116-0.133	....	38
71	*C. sinensis* (sweet orange)	Leaves	0.217-2.860	0.112-0.178	2.41-6.02	0.194-0.576	....	25,38,76,77
72		Leaves, yg.	1.55	0.18	4.34	0.12	0.230	22,23
73		Leaves, old	0.08	0.11	8.17	0.09	0.26	22,23
74		Twig bark	0.62	0.28	5.22	0.12	0.27	22,23
75		Twig wood	0.24	0.22	1.26	0.08	0.12	22,23
76		Trunk bark	0.66	0.24	4.40	0.35	0.18	22,23
77		Trunk wood	0.21	0.16	0.69	0.08	0.11	22,23
78		Root bark	0.75	0.24	3.26	0.18	0.20	22,23
79		Root wood	0.18	0.16	0.73	0.09	0.08	22,23
80		Small roots	0.158-1.248	0.25	0.457-0.507	0.220-0.779	0.14	22,23,38
81		Fruit rinds	0.225-1.310	....	0.544-1.010	0.08-0.16	....	38,39
82		Fruit pulp	0.695-2.950	....	0.060-0.394	0.088-0.180	....	38,39
83	*Cornus florida* (flowering dogwood)	Leaves	0.37-1.13	0.18-0.32	2.71-4.21	0.27-0.51	0.38-0.70	61
84	*C. mas* (cornelian cherry dogwood)	Fruits	1.685	0.118	0.224	0.075	0.154	12
85	*Cucumis sativus* (cucumber)	Fruits	4.46-4.51	0.450-1.153	0.518-0.689	0.307-0.331	0.366	12,21,94
86	*Cucurbita pepo* (pumpkin)	Fruits	0.711-2.86	0.240-0.633	0.244-0.500	0.09-0.26	0.042	7,12,94
87		Seed embryos	0.573	0.917	0.029	0.422	....	73

continued

III. PLANT TISSUES AND ORGANS: MINERAL COMPOSITION

Part I. MAJOR ELEMENTS

	Species (Common Name)	Plant Part	Potassium	Phosphorus	Calcium	Magnesium	Sulfur	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
				Dicotyledoneae				
88	*Daucus carota* (carrot)	Leaves	1.326	0.234	3.181	0.280	0.395	12
89		Shoots	2.43-3.37	0.197-0.289	1.29-3.29	0.219-0.386	0.073-0.477	62,78
90		Roots	1.677-5.920	0.306-0.468	0.376-0.502	0.121-0.235	0.141-0.156	12,62,72
91		Fruits	1.349	0.586	2.362	0.344	0.193	12
92	*Fagopyrum esculentum* (buckwheat)	Shoots	1.66-2.55	0.127-0.540	1.68-2.65	0.442-0.607	0.103-0.114	11,50
93		Shoots, fl.	2.11-3.17	0.219-1.02	1.97-3.15	0.29-1.22	0.121-0.298	7,9,11
94		Shoots, fr.	2.92	0.39	2.59	0.27	....	33
95		Straw	0.750-3.728	0.030-0.509	0.841-1.214	0.262-0.349	0.078-0.108	2,12
96		Fruits	0.262-0.539	0.240-0.447	0.044-0.171	0.103-0.229	0.012-0.037	2,12
97	*Fagus sylvatica* (European beech)	Leaves	0.450-0.822	0.176-0.178	1.022-2.048	0.173-0.221	0.037-0.103	12
98		Stems	0.128	0.029	0.262	0.034	0.007	12
99		Bark	0.144-0.429	0.016-0.044	1.394-2.310	0.087-0.189	0.001-0.0048	12
100		Heartwood	0.082-0.128	0.003-0.007	0.095-0.113	0.031-0.044	0.0012-0.0062	12
101		Sapwood	0.085-0.160	0.009-0.024	0.090-0.104	0.041-0.051	0.002-0.0077	12
102		Wood	0.014-0.141	0.011-0.030	0.071-0.096	0.029-0.039	0.0046-0.0054	12
103		Shoots	0.419	0.194	0.786	0.135	0.042	11
104		Involucres	0.016-0.886	0.013-0.066	0.152-0.503	0.030-0.062	0.010-0.037	12
105		Fruits	0.520-0.879	0.315-0.487	0.371-0.650	0.175-0.311	0.036-0.076	12
106		Fruit coats	0.228-0.276	0.019-0.036	0.497-0.965	0.048-0.068	0.018-0.040	12
107		Seeds	0.980-1.212	0.441-0.493	0.307-0.515	0.194-0.252	0.076-0.095	12
108	*Fraxinus excelsior* (European ash)	Leaves	1.087	0.692	1.973	0.343	0.197	12
109		Bark	0.285	0.070	2.355	0.058	0.025	12
110		Wood	0.040	0.0107	0.160	0.0128	0.0033	12
111		Seeds	1.56	0.282	0.661	0.168	0.154	12
112	*Glycine soja* (soybean)	Leaves	0.80	0.16	3.18	0.79	0.25	54
113		Stems	0.67	0.20	0.89	0.42	0.27	54
114		Shoots	0.54-2.31	0.09-0.74	0.52-2.18	0.16-0.86	0.125-0.520	7,32,57,62
115		Shoots, fr.	0.93	0.31	2.10	0.76	....	33
116		Shoots & roots	2.13-4.34	0.323-0.454	0.38-0.70	0.356-0.668	....	41
117		Roots	1.44-1.56	0.85-1.00	2.60-5.84	1.07-3.18	....	57
118		Fruits	1.95	0.51	0.56	0.41	0.22	54
119		Seeds	0.81-2.39	0.50-1.80	0.119-0.339	0.169-0.340	0.002-0.450	7,12
120	*Gossypium hirsutum* (upland cotton)	Shoots	0.875-2.110	0.230-0.429	0.97-2.17	0.108-0.690	0.260-0.332	26,28
121		Shoots, veg.	2.583-3.297	0.297-0.332	2.223-2.837	0.537-1.303	....	67
122		Shoots, fr.	1.013-1.503	0.166-0.205	1.444-1.515	0.362-0.585	....	67
123		Burs	1.42-5.74	0.07-0.21	0.44-1.02	0.19-0.34	....	42
124		Lint	0.46-0.75	0.025-0.124	0.013-0.27	0.07-0.11	0.04-0.06	7,26
125		Seeds	0.94-1.86	0.48-1.79	0.063-0.310	0.18-0.44	0.050-0.764	7,26,28
126	*Helianthus annuus* (common sunflower)	Leaves	1.620-1.899	0.237-0.350	6.324-7.640	1.097-3.150	0.430-0.660	12,93
127		Petioles	0.84	0.118	1.49	0.591	0.092	62
128		Stems	3.23	0.07	1.72	1.20	0.14	93
129		Upper	2.523	0.133	0.650	0.241	0.088	12
130		Lower	1.386	0.085	0.507	0.157	0.168	12
131		Shoots	0.46-2.76	0.14-0.25	0.485-3.160	0.219-0.501	0.037-0.238	10-12,57,62
132		Roots	1.361-3.800	0.10-0.34	0.371-2.160	0.132-1.270	0.34	12,57
133		Flowers	1.55	0.406	0.82	0.344	0.084	62
134		Fruits	0.98-3.24	0.326-0.497	0.300-0.979	0.162-0.300	0.188	12
135		Fruit coats	0.92	0.07	0.35	0.23	0.05	93
136		Head minus fruits	9.43	0.41	2.49	1.26	0.46	93
137		Seeds	0.96	1.01	0.129-0.21	0.398-0.40	0.02	73,93
138	*Ilex aquifolium* (English holly)	Leaves	0.51	0.068	0.783	0.381	0.013	12
139	*Ipomoea batatas* (sweet potato)	Leaves	1.61-2.37	0.19-0.28	0.71-1.18	0.45-0.54	....	32,55
140		Shoots	3.15-4.62	....	0.71	0.20	....	32,74
141		Roots	0.68-1.74	0.06-0.22	0.040-0.218	0.063-0.210	0.059-0.120	7,12,26,32
142	*Juglans nigra* (black walnut)	Leaves	1.98-2.45	0.32-0.54	1.06-3.23	0.35-0.50	0.01-0.23	61
143	*J. regia* (Persian walnut)	Seeds	0.188-0.550	0.407-0.450	0.071-0.131	0.168-0.178	0.009	12
144	*Lactuca sativa* (lettuce)	Leaves	2.69-7.91	0.19-1.05	0.330-1.892	0.040-0.709	0.25-0.31	7,12

continued

111. PLANT TISSUES AND ORGANS: MINERAL COMPOSITION

Part I. MAJOR ELEMENTS

	Species (Common Name)	Plant Part	Potassium	Phosphorus	Calcium	Magnesium	Sulfur	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Dicotyledoneae							
145	*Lycopersicon esculentum* (tomato)	Leaves	0.518-3.760	0.160-0.724	2.280-8.702	0.620-1.547	0.164	6,11,48,56,86,87
		Leaf blades						
146		Upper	2.670-3.492	0.800-0.808	1.610-1.747	0.670-0.681	0.98	65,66,68
147		Middle	3.763	0.822	3.633	1.210	....	68
148		Lower	2.67-3.20	0.500-0.780	3.840-6.033	0.990-1.954	1.45	65,66,68
		Petioles						
149		Upper	6.27-7.22	0.730-0.752	1.080-1.557	0.920-1.078	0.38	65,66,68
150		Middle	6.734	0.891	2.421	1.669	....	68
151		Lower	3.200-6.471	0.690-1.099	2.230-3.252	1.640-2.646	0.49	65,66,68
152		Stems	1.35-5.30	0.099-0.540	1.360-2.321	0.470-0.652	0.18	11,48,56,86,87
153		Upper	5.250-6.006	0.620-0.700	0.670-0.910	0.552-0.690	0.33	65,66,68
154		Middle	4.753	0.689	1.366	0.750	....	68
155		Lower	2.270-3.450	0.410-0.703	0.990-2.084	0.500-0.995	0.28	65,66,68
156		Shoots, veg.	4.466	0.786	2.738	1.205	....	68
157		Roots	0.796-3.41	2.34-2.45	1.26	0.46	0.75	56,65,66
158		Fruits	1.88-5.90	0.29-0.84	0.08-0.48	0.13-0.59	0.14-0.45	6,7,12,45,56,87
159		Fruits, un.	1.895	0.354	0.129	0.152	....	6,7,12,45,56
160		Seeds	0.238-0.465	0.686	0.20	0.410	....	45,65
161	*Magnolia macrophylla* (big-leaf magnolia)	Leaves	1.25-3.30	0.18-0.48	0.09-2.38	0.30-0.41	0.02-0.29	61
162	*Malus sylvestris* (apple)	Leaves	0.49-3.92	0.090-0.749	0.61-2.67	0.11-0.78	....	4,13-15,18,50,51,64,71,81,88-90
163		Stems	0.71-1.39	....	0.60-1.14	0.09-0.33	....	18,88
164		Fruits	0.427-1.410	0.019-0.680	0.023-0.129	0.018-0.098	0.022-0.090	7,12,72
165		Fruit flesh	0.62-0.90	0.055-0.113	0.021-0.177	0.047	0.021	7,12
166		Seeds	0.828	0.705	0.250	0.355	0.047	12
167	*Medicago sativa* (alfalfa)	Shoots	0.702-4.030	0.153-0.713	0.55-3.49	0.060-1.020	0.188-0.400	5,6,11,29,34,62,78,83
168		Shoots, veg.	....	0.315	2.05	....	....	10
169		Shoots, e.fl.	1.443	0.248-0.410	1.63-3.12	0.219	0.170	10,11,36
170		Shoots, full fl.	0.55-4.29	0.14-0.51	0.59-4.15	0.17-0.37	0.20-0.32	7,10,36,84
171	*Nicotiana tabacum* (common tobacco)	Leaves	0.51-7.81	0.12-0.55	1.20-6.07	0.03-2.74	0.18-1.19	7,12,26,28,32
172		Upper	3.40	0.291	4.18	0.93	0.185	12
173		Lower	4.55	0.260	3.87	0.91	0.185	12
174		Stems	1.900-4.026	0.140-0.491	0.54-2.97	0.039-0.920	0.109-0.310	12,26,28,32
175		Seeds	1.285	0.622	0.243	0.334	0.018	12
176	*Pastinaca sativa* (garden parsnip)	Roots	0.86-2.62	0.20-0.84	0.250-0.395	0.120-0.166	0.101	7,12
177	*Phaseolus vulgaris* (kidney bean)	Fruits	1.49-3.23	0.20-0.84	0.41-1.21	0.05-0.52	....	7
178		Fruit coats	2.58	0.553	0.671	0.341	0.191	60
179		Seeds, im.	2.00	0.744	0.274	0.324	0.868	60
180		Seeds	1.176-1.890	0.412-0.500	0.104-0.179	0.148-0.200	0.052-0.227	12,60
181	*Pisum sativum* (garden pea)	Shoots	1.69	0.336	1.54	0.489	0.328	62
182		Shoots, fl.	2.31	0.358	1.34	0.459	0.246	11
183		Fruit coats	1.959	0.214	2.51	0.307	0.268	62
184		Seeds	0.814-0.977	0.380-0.607	0.057-0.114	0.127-0.163	0.037-0.156	12,62
185	*Populus tremula* (European aspen)	Leaves	1.353	0.341	3.147	0.212	0.101	12
186		Bark	0.214-0.351	0.021-0.045	0.641-1.732	0.143-0.156	0.0098-0.031	12
187		Wood	0.039-0.167	0.007-0.0076	0.069-0.202	0.009-0.034	0.0016-0.0051	12
188	*Prunus amygdalus* (almond)	Seeds	0.223-1.137	0.442-0.934	0.206-0.309	0.225-0.522	0.007-0.046	12
189	*P. domestica* (garden plum)	Fruits	0.895	0.120	0.131	0.060	0.028	12
190		Fruit without seed	1.126-1.426	0.107-0.118	0.061-0.108	0.050-0.054	0.021-0.057	12
191		Fruit skin	1.158	0.138	0.140	0.133	0.018	12
192		Fruit flesh	0.765-1.109	0.087-0.181	0.081-0.144	0.059-0.077	0.030	12
193		Seed	0.902	0.624	0.249	0.400	0.117	12
194		Endocarp	0.047	0.003	0.052	0.006	0.0007	12

continued

Part I. MAJOR ELEMENTS

	Species (Common Name)	Plant Part	Potassium	Phosphorus	Calcium	Magnesium	Sulfur	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Dicotyledoneae							
195	*Prunus persica* (peach)	Leaves	0.76-2.35	0.092-0.720	1.06-2.71	0.410-1.450	....	50
196		Fruit without seed	1.269-1.644	0.161-0.227	0.041-0.091	0.057-0.069	0.027-0.063	12
197		Fruit flesh	1.53-2.44	0.184-0.205	0.079-0.229	0.094-0.109	....	12
198	*Pyrus communis* (pear)	Fruits	0.894-0.938	0.105-0.131	0.066-0.112	0.052-0.062	0.040-0.045	12
199		Fruit without seed	0.790	0.094	0.061	0.047	0.036	12
200		Fruit flesh	0.512	....	0.074	0.055	....	12
201		Seeds	0.688	0.628	0.215	0.335	0.045	12
202	*Quercus robur* (English oak)	Leaves	0.963	0.187	0.652	0.286	0.038	12
203		Bark	1.191	0.060	1.722	0.095	0.018	12
204		Bast and cambium	0.298-0.395	0.012-0.016	2.79-3.93	0.021-0.092	0.0069-0.010	12
205		Outer bark	0.096-0.190	0.0064-0.012	1.865-5.50	0.082-0.435	0.0046-0.0062	12
206		Heartwood	0.048-0.088	0.0015-0.0056	0.0[illegible]-0.058	0.003-0.0074	0.002-0.0079	12
207		Sapwood	0.075-0.162	0.0114-0.031	0.050-0.094	0.0095-0.023	0.0035-0.0116	12
208		Wood	0.140	0.036	0.078	0.048	0.005	12
209		Fruits	1.161	0.142	0.108	0.069	0.036	12
210	*Raphanus sativus* (garden radish)	Leaves	2.270	0.272	3.095	0.452	0.516	12
211		Roots	1.924-2.859	0.343	0.773-0.983	0.135-0.334	0.187-0.484	12
212	*Rheum palmatum* (sorrel rhubarb)	Leaf blades	0.829	0.106	0.196	0.105	....	12
213		Petioles	0.953-7.146	0.929-1.079	0.224-1.036	0.267	0.109-0.302	12
214		Leaves	7.144	0.891	1.036	....	0.109	12
215		Leaves and stems	3.39	0.099	2.75	0.893	....	12
216		Roots	1.72	0.102	1.39	0.376	....	12
217	*Ribes nigrum* (European black currant)	Leaves	0.91-1.06	....	....	0.26-0.45	....	90,92
218		Fruits	0.96-1.67	0.275-0.374	0.190-0.531	0.080-0.146	0.094-0.121	12
219	*Rosa centifolia* (cabbage rose)	Petals	1.277-1.369	0.194-0.255	0.151-0.226	0.133-0.151	0.080-0.110	12
220	*Salix viminalis* (basket willow)	Leaves	1.013	0.052	1.722	0.585	0.328	12
221		Stems	0.272-0.332	0.050-0.073	0.489-0.538	0.040-0.082	0.029-0.030	12
222		Bark	0.732-1.024	0.017-0.170	0.886-1.247	0.095-0.205	0.068-0.072	12
223		Wood	0.307	0.026	0.207	0.084	0.016	12
224	*Solanum tuberosum* (potato)	Leaves	2.10-6.79	....	1.08	0.231-0.860	....	20,32,47,52, 64,91
225		Shoots	0.03-4.19	0.083-0.260	0.58-4.12	0.220-1.15	0.152-0.68	26,32,62,85
226		Tubers	1.05-3.96	0.11-0.49	0.017-0.290	0.05-0.23	0.06-0.42	7,12,26,32,44, 62,63,72
227	*Trifolium pratense* (red clover)	Leaves	1.846-1.969	0.231-0.337	2.030-2.759	0.468-0.710	0.042-0.052	12,31
228		Petioles	2.630	0.481	2.157	0.612	0.059	12
229		Stems	1.678-1.958	0.122-0.320	1.086-1.284	0.389-0.454	0.039-0.058	12,31
230		Shoots	0.66-2.82	0.11-0.52	0.61-3.07	0.13-0.75	0.05-0.29	7,62,78
231		Shoots, veg.	2.16-2.99	0.320-0.529	1.92-2.02	0.510-0.559	0.088	11,43
232		Shoots, fl.	1.11-3.41	0.210-0.290	1.07-2.12	0.35-0.68	0.089-0.190	7,11,72
233		Shoots, fr.	0.974-1.840	0.226-0.392	1.33-2.03	0.494-0.602	0.064-0.160	7,72
234		Flowers	1.497-2.111	0.376-0.495	1.163-1.193	0.404-0.455	0.056-0.060	12,31
235		Seeds	1.321	0.746	0.206	0.350	0.043	12
236	*Ulmus americana* (American elm)	Leaves	0.59-2.03	0.13-0.59	1.40-2.45	0.41-0.57	0.02-0.35	61
237	*Vicia faba* (broad bean)	Shoots	2.09	0.267	0.917	0.211	0.140	62
238		Shoots, veg.	....	0.277-0.357	1.38-1.70	....	....	10
239		Shoots, fl.	....	0.226-0.246	1.24-1.35	....	....	10
240		Fruit coats	2.291-3.450	0.109-0.138	0.567-0.829	0.187-0.422	0.052-0.058	12,62
241		Seeds	1.250-1.312	0.585-0.616	0.129-0.143	0.145-0.157	0.049-0.092	12,62
242	*Vitis vinifera* (European grape)	Leaves	0.585-0.984	0.077-0.198	1.822-2.846	0.238-0.426	0.095-0.111	12
243		Stems	0.759	0.135	0.642	0.099	0.041	12
244		Fruits	0.838-2.422	0.191-0.353	0.078-0.399	0.040-0.132	0.028-0.117	12
245		Seeds	0.594-0.648	0.333-0.343	0.451-0.680	0.097-0.122	0.036-0.067	12

Contributor: McIlrath, Wayne J.

continued

III. PLANT TISSUES AND ORGANS: MINERAL COMPOSITION

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Part II. MINOR ELEMENTS

Many of the ranges cover a vast literature, but because of space limitations only the more recent references (which frequently cite the earlier literature) have been included. Values are mg/kg of dry weight.

	Species (Common Name)	Plant Part	Boron	Copper	Iron	Manganese	Zinc	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Monocotyledoneae							
1	*Allium cepa* (garden onion)	Bulbs	....	2-24	24-265	2-96	100	21,93,121,143,144
2	*Aspa agus officinalis* (garden asparagus)	Shoots, vg.	....	7-17	60-979	12-29	52	21,40,88,121
3	*Avena sativa* (common oat)	Leaves	....	......	....	12-240	19-276	2,66,94,95,169
4		Shoots	....	0.7-17	....	5-93	4-29	93,139,140
5		Shoots, veg.	....	4-12	....	79-90	18-40	138,139
6		Shoots, fl.	15-50	3-4	50-270	5-82	12-25	27,28,44,82,138,139
7		Shoots, fr.	2-17	1-9	154	5-116	12-13	41,127,138,139,148
8		Straw	8	2-54	61-860	4-1,656	4-193	45,53,84,109,139
9		Grain	1-19	0.7-51	7-350	14-76	22-40	45,53,84,139,169
10	*Hordeum vulgare* (barley)	Shoots	4-53	14	[illegible]0-450	....	......	44,93,127,130
11		Grain	0.6-13	1-70	14-350	7-38	21-132	8,15,60,114,151
12	*Lilium* spp. (lily)	Stigmas	13-14	......	....	2	......	31-35
13		Anthers	8-13	......	....	2	......	31-35
14	*Oryza sativa* (rice)	Roots	....	8-16	....	430	......	45,149
15		Grain	9.4	3-4	76-350	18-70	30	18,45,105,149,151
16	*Phleum pratense* (timothy)	Shoots	10-16	2-7	30-287	11-165	30-60	13,43,127,155
17		Grain	....	......	61-410	72	......	45,98
18	*Phoenix dactylifera* (date palm)	Pinnae	73-172	......	....	....	......	70
19		Fruit flesh	8-18	2-5	35-70	2-54	4	17,18,21,52,70,91,92,135
20	*Poa pra[illegible]sis* (Kentucky bluegrass)	Leaves, veg.	3	14	....	80	170	60,102
21		Shoots	6-12	......	60-425	29-216	17-28	100,104,108,154,155,158
22		Grain	....	60	350-460	85-110	360	45,98,102
23	*Triticum aestivum* (wheat)	Shoots	3-10	3-12	290-580	....	13-25	38,39,41,44,93,139
24		Straw	9-10	1-18	60-630	22-150	7-25	13,21,61,84,108,114
25		Grain	1-11	3-24	3-420	5-260	19-105	8,13,15,79,84,108,123,160
26	*Zea mays* (corn)	Leaves	27-72	......	41-810	230-440	......	14,60,80,87
27		Stems	....	......	400-740	100-230	......	87
28		Roots	....	......	500-760	450-880	......	87
29		Shoots	15-18	......	312-321	52-200	......	126,158
30		Stover	....	2-9	94-345	54-270	5-80	13,61,151,155
31		Kernels	1-9	4-30	13-550	5-500	20	8,17,18,21,121,151
32		Cobs	....	......	250	310	......	87

continued

III. PLANT TISSUES AND ORGANS: MINERAL COMPOSITION

Part II. MINOR ELEMENTS

	Species (Common Name)	Plant Part	Boron	Copper	Iron	Manganese	Zinc	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Dicotyledoneae							
33	*Acer saccharum* (sugar maple)	Leaves	....	11-12	150-440	40-220	24-54	107,145
34		Twigs	....	......	55	170	....	145
35		Bark	....	......	86	261	....	145
36		Sapwood	....	......	27	59	....	145
37		Heartwood	....	......	18	55	....	145
38	*Beta vulgaris* (beet)	Leaves	7-29	9-18	142-1,932	16-205	....	91,121,126,143
39		Roots	2-46	6-27	69-290	19-104	25-69	13,21,54,84,143
40	*Capsicum frutescens* (bush red pepper)	Leaves	34-118	......	....	....	....	60
41		Fruits	21	8-18	....	13-70	....	54,60
42		Fruit flesh	....	16	57-630	18-19	....	7,92,117,121,135,137
43	*Carya illinoensis* (pecan)	Leaves	....	21-28	144-185	....	4-202	1,64,65
44		Seeds	3	14	26	36	....	13,104,135,137
45	*Catalpa speciosa* (northern catalpa)	Leaves	....	18-21	330-680	80-130	28-50	107
46	*Citrus limon* (lemon)	Leaves	19-200	2-13	288	14-75	....	51,73,74
47		Fruit rinds	23-35	3-4	60	....	....	71,74,135
48		Fruit pulp	12-26	5	420	3	....	29,30,71,74,117
49	*C. sinensis* (sweet orange)	Leaves	17-386	7-18	38-345	24-46	24-47	50,71,73,89,156,157
50		Roots	95	......	....	....	240	50
51		Fruits	22-27	3-4	....	....	....	71,74
52		Fruit rinds	10-27	6	....	....	....	71,73,74,104,152
53		Fruit pulp	10-38	1-31	19-70	3	12	21,30,71,73,74,120
54	*Cornus florida* (flowering dogwood)	Leaves	23	7-9	240-380	30-50	3-28	104,107
55	*Cucumis sativus* (cucumber)	Fruits	....	5-30	33-420	24-48	44	21,91,121,137
56	*Cucurbita pepo* (pumpkin)	Fruits	....	11	....	13	....	67,81
57		Fruit flesh	....	......	....	4	44	20,21,137
58	*Daucus carota* (carrot)	Shoots	20-45	5-10	355-765	23-199	26	21,57,127,143
59		Roots	21-57	5-20	39-490	6-91	10	13,21,54,60,93,121,143
60	*Fagopyrum esculentum* (buckwheat)	Shoots	....	......	100	14	15	27,28
61		Fruits	....	......	34-170	....	12	20,21,45,135
62	*Fragaria* spp. (strawberry)	Fruits & floral receptacles	....	2-8	68-267	6-40	4	21,91,92,120
63	*Fraxinus americana* (white ash)	Leaves	....	......	195	94	....	146
64		Twigs	....	......	55	27	....	146
65		Bark	....	......	78	96	....	146
66		Sapwood	....	......	15	Trace	....	146
67		Heartwood	....	......	16	Trace	....	146
68	*Glycine soja* (soybean)	Leaves	30-148	8	336	29-192	110	78,99,127,158,159
69		Stems	8-38	......	....	7-20	....	78,127,158
70		Shoots	1-13	4-12	100-570	45-280	28-80	13,55,61,125,155
71		Roots	14-16	......	....	17-147	....	127,158,159
72		Seeds	6-41	12-23	57-161	14-41	18	61,99,121,127,158
73	*Gossypium* spp. (cotton)	Leaves	60-795	......	1,754	80-100	....	45,60,86,113
74		Stems	6-186	......	610	40-50	....	45,86,113
75		Lint	....	......	190	11-190	....	86,101
76		Seeds	27-130	54	150-590	13-31	320	45,86,101,113
77	*Helianthus annuus* (common sunflower)	Shoots	12-150	......	....	72-1,268	....	114,128,161
78		Fruits	....	......	34	23	19	20,21,98
79	*Ilex opaca* (American holly)	Leaves	....	6-14	200-270	260-540	130-240	107
80	*Ipomoea batatas* (sweet potato)	Tuberous roots	4-44	3-9	11-140	3-28	5	21,54,60,121,122,143
81	*Juglans* spp. (walnut)	Seeds	15	8	200	19-33	....	8,45,81,92,104
82	*J. nigra* (black walnut)	Leaves	40-67	11	280-780	60-190	26-49	107,147
83	*Lactuca sativa* (garden lettuce)	Leaves	13-75	3-33	65-4,830	15-523	105-119	13,19,54,93,118,121,143
84	*Lycopersicon esculentum* (common tomato)	Leaflets	92-147	12	277-542	70-398	17-30	96,97,134
85		Leaves	21-150	12-21	106-840	53-4,930	....	14,47,60,90,127,147
86		Stems	21-26	6-13	110-230	14-45	....	90,147
87		Shoots	24	11-12	2,000	32-100	....	9,68,77
88		Fruits	13-36	4-34	32-800	2-410	2-67	13,54,60,90,97,103,143
89	*Magnolia macrophylla* (big-leaf magnolia)	Leaves	....	6-8	150-230	29-30	19-62	107
90	*Malus sylvestris* (apple)	Leaves	11-43	3-12	65-507	20-156	4-345	12,46,48,164
91		Stems	9-21	......	....	....	16-80	49,110,170
92		Fruits	3-76	5-7	1-69	1-22	3-9	10,21,76,91,92,117

continued

111. PLANT TISSUES AND ORGANS: MINERAL COMPOSITION

Part II. MINOR ELEMENTS

	Species (Common Name)	Plant Part	Boron	Copper	Iron	Manganese	Zinc	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Dicotyledoneae							
93	*Medicago sativa* (alfalfa)	Leaves	4-654	......	....	45-76	....	59,60,83,111
94		Shoots	12-128	4-61	110-675	10-124	13-112	11,13,63,100
95		Shoots, veg.	29	80	140-410	29-101	37	41,139,148,167
96		Shoots, fl.	25-50	......	161-1,000	14-936	14	16,27,28,167
97		Seeds	10	......	....	6-15	....	17,18,36,80,98,142
98	*Nicotiana* spp. (tobacco)	Leaves	6-93	17	70-2,100	48-2,262	....	6,14,61,80,124,129
99		Seeds	6	......	240	70	....	98,104
100	*Pastinaca sativa* (garden parsnip)	Roots	....	7	46-210	....	....	91,117,135,136
101	*Persea* spp. (persea)	Fruits	36-132	......	12-575	....	....	69,117,120,165
102	*Phaseolus vulgaris* (kidney bean)	Shoots, fr.	....	......	1,350	124	....	148
103		Plant	6-12	......	....	32-68	....	60,133
104		Fruits	2-37	6-20	52-769	11-57	8	13,21,54,143,163
105		Fruit coats	22-40	12	270	39	53	106,127
106		Seeds, im.	....	10	80-270	16-19	46	13,98,106
107		Seeds	17	......	120	20	....	17,18,36,148
108	*Pisum sativum* (garden pea)	Leaves	16	......	....	38	....	60,83
109		Shoots	17-22	......	....	15	....	22-26,81
110		Fruits	....	7-12	....	21-27	....	81,83,116,144
111		Seeds	2-8	6-15	70-282	4-25	40-48	57,85,104,142,166
112	*Prunus amygdalus* (almond)	Seeds	15-57	11-13	42-190	13	21	21,72,85,91,137
113	*P. domestica* (garden plum)	Leaves	....	7-10	....	55-93	....	3,62
114	*P. persica* (peach)	Leaves	17-81	......	....	17-325	6-345	4,49,60,62,112
115		Stems	7-44	......	....	....	11-50	49,60,112
116		Fruits	38-52	......	140	....	2	20,21,58,104,117
117	*Pyrus communis* (pear)	Leaves	....	5-41	28-94	....	....	14,80,119,131,132
118		Bark	....	4-17	53-120	....	....	119,132
119		Wood	....	2-12	5-20	....	....	119,132
120		Fruit	19	6-13	29-140	2-4	9	21,58,91,92,117
121	*Quercus velutina* (black oak)	Leaves	....	7-9	250-280	490-1,870	36-68	107
122	*Raphanus sativus* (garden radish)	Leaves	20-196	......	141-224	....	....	60,126
123		Roots	17-152	29	97-825	14-45	23	21,60,89,117,126,137
124	*Rheum* spp. (rhubarb)	Petioles	....	9	154-680	31	22	20,21,91,117,135,137
125	*Ribes* sp. (currant)	Fruits	19-58	17	80-420	4	....	45,58,91,92
126	*Solanum tuberosum* (potato)	Leaves	20-98	30-89	....	....	....	56,60,84
127		Shoots	14-39	11	....	86-108	....	38,39,41,43,57,114
128		Tubers	2-22	0-28	28-363	3-94	11-14	13,21,54,84,114,141
129	*Trifolium pratense* (red clover)	Leaves	57	......	....	40-84	....	42,83
130		Stems	28	......	....	15-20	....	42,83
131		Shoots	31-36	6-20	100-1,300	25-542	24-80	13,63,93,104
132		Shoots, veg.	23-58	......	....	....	....	41
133		Shoots, fl.	19-109	......	....	287	....	41,148
134		Flowers	40	......	....	30-66	....	42,83
135		Seeds	....	17	21-336	6-38	76	13,83,98,100
136	*Ulmus americana* (American elm)	Leaves	277	7-16	245-810	39-130	10-22	60,107,146
137		Twigs	14	......	68	20	....	60,146
138		Bark	....	......	145	30	....	146
139		Sapwood	....	......	48	9	....	146
140		Heartwood	....	......	22	2	....	146
141	*Vicia faba* (broad bean)	Shoots	....	......	280	36	....	114,168
142		Straw	....	......	63	23	....	114,168
143		Seeds	11-223	10-11	21	14-15	....	37,67,114
144	*Vitis* spp. (grape)	Leaves	16-2,084	3-47	190-220	180-220	....	75,115,162
145		Stems	5-50	15-16	28-33	37-46	....	60,115,153
146		Fruits	15-34	5-10	13-530	Trace	2	5,13,21,92,150

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XI. ENVIRONMENT AND SURVIVAL

112. HIBERNATION: MAMMALS AND BIRDS

Hibernation in homiotherms is a lethargic condition characterized by a lowering of the temperature of the body to approximately the temperature of the environment--with a concurrent reduction in metabolism--and the resumption of the elevated temperature at some future time without the aid of heat from external sources.

	Species (Common Name)	Distribution	Temperature °C		Heart Rate beats/min	Respiration Rate breaths/min	O_2 Consumption ml/g body wt/hr	CO_2 Production ml/g body wt/hr	RQ[1]	Reference
			Air	Rectal						
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Mammalia									
1	*Citellus citellus* (suslik)	Central Asia, southern Russia to Austria	.....	6	.....	....	0.320	0.230[2]	0.72	15
2			7	7.2	.....	....	0.015	.....	...	14
3			11	11.7	.....	5	....	.....	...	9
4			13	15.5	.....	....	0.034	.....	...	20
5	*C. tridecemlineatus* (thirteen-lined ground squirrel)	Central United States, Canada	.....	3-10[3]	5-20	14-15	0.081-0.191	.....	...	1,10
6			4.0	5.7	.....	1	0.081	.....	...	11
7			8.6	10.2	.....	1.6	0.125	.....	...	11
8			12.5	13.6	.....	1.8	0.197	.....	...	11
9	*C. undulatus* (Arctic ground squirrel)	Alaska, northern Canada, northeastern Siberia	.....	5.2	68[4]	10	....	.....	...	8
10			5.9	5.9	.....	6	....	.....	...	8
11	*Eptesicus fuscus* (big brown bat)	United States, southern Canada	8	9	.....	3-10[5]	....	.....	...	21
12			22-26	....	.....	....	0.8	.....	...	8
13	*Erinaceus europaeus* (European hedgehog)	Great Britain to Spain, Italy, Greece	2-3	6.2-7.7	18-24	....	0.014-0.033	.....	...	26,27
14			3.5	5	.....	....	0.88	0.83	0.68	5
15			6	....	.....	....	0.40	0.29[2]	0.73	15
16			9.7	12.0	.....	....	0.126	0.056	...	5
17	*Glis glis* (fat dormouse)	Central and southern Europe	6	....	.....	....	0.029	0.021[2]	0.72	15
18			11.8	....	.....	....	0.024	.....	...	14
19	*Marmota marmota* (Eurasian marmot)	Alps	10	10.5	.....	0.35[5]	0.018	0.012	0.68	14
20	*M. monax* (woodchuck)	Eastern United States, Canada, Alaska	.....	4-7	4-5	....	0.008-0.034	.....	...	2
21			1.2	5.8	.....	16	....	.....	...	8
22			8	8	.....	6	....	.....	...	8
23	*Mesocricetus auratus* (golden hamster)	Rumania, eastern Asia Minor, Syria, Palestine, northwestern Iran	5	5-6	.....	....	0.183	0.132[2]	0.72	16
24			5.5	5.5[3]	.....	....	0.032	.....	...	18
25			5.8	6.4[3]	.....	....	0.06	.....	...	18
26			5	5	4-15	....	0.060-0.080	.....	...	18,19
27	*Muscardinus avellanarius* (common dormouse)	Southern Italy to England and Sweden	6	....	.....	9-10	....	.....	...	25
28			10.1	....	.....	....	0.80	0.57[2]	0.71	14
29			11.6	....	10-12	....	....	.....	...	28
30	*Myotis keenii* (long-eared little brown bat)	Eastern United States, British Columbia	21.5	22.7[6]	.....	140-168	0.85	.....	...	8
31	*M. lucifugus* (little brown bat)	Northern United States, southern Canada, southern Alaska	0.5	....	.....	....	0.113	.....	...	7
32			.....	2	7-10	....	0.022-0.039	.....	...	7,24
33			10	....	.....	....	0.071	.....	...	7
34			23	23.2[6]	.....	72-80	0.45	.....	...	7
35	*M. myotis* (common brown bat)	Europe to China to Afghanistan	1.7	....	.....	....	0.020	0.009	...	6
36			2.5	....	.....	....	0.051	0.033	0.65	6
37	*Nyctalus noctula* (noctule bat)	Europe to Siberia, Japan to Palestine	4.3	....	.....	....	0.51	0.38[2]	0.75	15
38			12.5	....	.....	....	3.49[7]	2.58[2]	0.74	15
39			20	....	.....	....	0.403[2]	0.314	0.78	13
40			30	....	.....	....	0.682[2]	0.484	0.71	13
41	*Pipistrellus pipistrellus* (European brown bat)	Europe to northern Asia, Japan	.....	5	.....	....	0.247	0.175[2]	0.71	15
42			5	....	.....	....	0.053	0.038[2]	0.72	15

/1/ Respiratory quotient. Probably does not reflect actual exchange of gases or the true nature of combustion of foods during hibernation. /2/ Calculated. /3/ Oral temperature. /4/ Feeble heart beat in deep hibernation, becoming more evident as awakening progresses. /5/ Respiration rates are very irregular in deep hibernation, and there may be several minutes with no respiration followed by several respirations. Cheyne-Stokes respiration is not uncommon; range is average of several minutes. /6/ Subcutaneous temperature. /7/ During awakening from hibernation.

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112. HIBERNATION: MAMMALS AND BIRDS

	Species (Common Name)	Distribution	Temperature °C		Heart Rate beats/min	Respiration Rate breaths/min	O_2 Consumption ml/g body wt/hr	CO_2 Production ml/g body wt/hr	RQ[1]	Reference
			Air	Rectal						
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Mammalia									
43	*Plecotus auritus* (long-eared bat)	Europe to Japan, eastern Siberia to Sudan	0	....	.....	....	0.037	.....	...	4
44			5	6.5	.....	....	0.069	0.049[2]	0.71	13
45			10	10.7	.....	....	0.094	0.079[2]	0.84	13
46			19.7	....	.....	....	0.255	.....	...	12
47	*Rhinolophus ferrum-equinum* (greater horseshoe bat)	England to Korea, Japan to Morocco	13	13	.....	....	0.150	0.089	...	3
48			19	19	.....	....	0.426	0.366	0.77	3
49	*R. hipposideros* (lesser horseshoe bat)	Europe to Asia Minor, northwestern India to Sudan	15	15	.....	....	2.23	1.80	0.80	3
50	*Ursus americanus* (black bear)[8]	N. America (north of Mexico)	4.4	35.5	.....	2-3	....	.....	...	29
51	*Vespertilio murinus* (parti-colored bat)	Europe to Japan, northwestern India	0	....	.....	....	....	0.037	...	4
52			7.05	7.05	50-55	....	....	.....	...	23
53			8	....	.....	....	....	0.020	...	4
	Aves									
54	*Apus apus* (swift)	N. America, Europe, Africa, Asia	19	23[9]	.....	8-10[5]	0.7	0.31	...	17
55	*Calypte anna* (Anna's hummingbird)	United States (California)	24	....	.....	....	0.84	.....	...	22
56	*Selasphorus sasin* (Allen's hummingbird)	United States (California)	22	....	.....	....	1.24	.....	...	22

/1/ Respiratory quotient. Probably does not reflect actual exchange of gases or the true nature of combustion of foods during hibernation. /2/ Calculated. /5/ Respiration rates are very irregular in deep hibernation, and there may be several minutes with no respiration followed by several respirations. Cheyne-Stokes respiration is not uncommon; range is average of several minutes. /8/ Not a true hibernator, as indicated by the discrepancy between rectal and ambient temperature. /9/ Proventricular temperature, taken orally.

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113. DIAPAUSE: INSECTS AND MITES

Diapause in insects and mites may be facultative (influenced by the environment and not present in each generation) or obligate (occurring in virtually every individual and in each generation without respect to environment). Species experiencing facultative diapause generally complete two or more generations annually (bivoltine or multivoltine cycles), whereas those with obligate diapause produce one generation (univoltine cycle). **Dormant Stage** (column B): I = instar; FI = final instar; FD = fully developed; S = small; HG = half-grown.

	Species (Common Name)	Dormant Stage	Diapause Type	Diapause Duration	Reference
	(A)	(B)	(C)	(D)	(E)
	Insecta				
1	*Aedes hexodontus* (mosquito)	Embryo (FD)	Obligate	Throughout winter	5
2	*A. tristeriatus* (mosquito)	Embryo (FD)	Facultative	Up to 6 months	3
3	*Anax imperator* (darner)	Larva (FI)	Facultative	2-3 months	13
4	*Anthrenus verbasci* (varied carpet beetle)	Larva (S-FI)	Obligate	Many months	7
5	*Apanteles glomeratus* (little braconid)	Prepupa	Facultative	....	19
6	*Bombyx mori* (silkworm)	Embryo (S or HG)	Facultative[1] or obligate[2]	5-9 months	22
7	*Cephus cinctus* (wheat stem sawfly)	Prepupa	Obligate	6-8 months	31
8	*Ceratophyllus fasciatus* (European rat flea)	Larva (FI)	Obligate	2-12 months	2
9	*Drosophila deflexa* (fruit fly)	Larva (FI)	Facultative	Several months	4
10	*Dytiscus marginalis* (diving beetle)	Adult	Obligate[3]	....	21
11	*Ephestia elutella* (tobacco moth)	Larva	Facultative	8-9 months	34
12	*Epilachna corrupta* (ladybird beetle)	Adult	Facultative	Throughout winter	17
13	*Eurydema ornatum* (ornate vegetable bug)	Adult	Facultative	....	10
14	*Eurygaster integriceps* (soun pest)	Adult	Obligate	....	18
15	*Leptinotarsa decemlineata* (Colorado potato beetle)	Adult	Facultative[3]	Many months	11,12
16	*Lestes sponsa* (damselfly)	Egg	Obligate	15 weeks	14
17	*Locusta migratoria gallica* (migratory locust)	Egg	Obligate	14-156 days	23
18	*Malacosoma disstria* (forest tent cat rpillar)	Embryo (FD)	Obligate	6-9 months	20
19	*Melanoplus bivittatus* (two-striped grasshopper)	Embryo (FD)	Obligate	Few weeks to many months	32
20	*M. differentialis* (differential grasshopper)	Egg	Obligate	Few weeks to many months	8,9
21	*Melittobia chalybii* (chalcid)	Larva (FI)	Facultative	Several months	33
22	*Phaenicia sericata* (greenbottle fly)	Larva (FI)	Facultative	Several wee to many mont s	15,29
23	*Pieris rapae* (imported cabbageworm)	Pupa	Facultative	6-52 weeks	28
24	*Popillia japonica* (Japanese beetle)	Larva (3rd I)	Facultative	50 days	25,26
25	*Pyrausta nubilalis* (European corn borer)	Larva (FI)	Facultative[1] or obligate[2]	6-9 months	1
26	*Reduvius personatus* (masked hunter)	Larva	Obligate	Few weeks to several months	30
27	*Samia cynthia* (cynthia moth)	Pupa	Facultative	....	16
28	*Trichogramma cacaeciae* (fairyfly)	Larva (FI)	Facultative	6-8 months	27
	Acari				
29	*Metatetranychus ulmi* (European red mite)	Egg	Facultative	....	6,24
30	*Tetranychus telarius* (two-spotted spider mite)	Adult	Facultative	....	24

/1/ Bivoltine strains. /2/ Univoltine strains. /3/ Reproductive diapause involving corpus allatum.

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113. DIAPAUSE: INSECTS AND MITES

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114. DISPERSION OF SMALL ORGANISMS

Units Dispersed (columns C-G): Values are means.

Part I. INVERTEBRATES

Dispersion by flight may possibly be aided by air movements.

	Invertebrate (Common Name) [Means of Dispersion]	Distances and Units Dispersed						Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Horizontal Dispersion							
1	*Aedes* spp. (mosquito) [flight]	Miles from original case Yellow fever cases	17.5 14.6	32.5 4.6	47.5 1.7	62.5 0.8	92.5 0.6	91
2	*A. aegypti* (yellow-fever mosquito) [flight]	Meters from release point Eggs in traps	250 1,100	750 46	1,250 40	1,750 5	2,250 2	98
3	*A. albopictus* (mosquito) [flight]	Yards from release point Mosquitoes recovered	25 92	125 43	225 2	325 1	475 2	5
4	*A. communis* (mosquito) [flight]	Feet from release point (subarctic) Mosquitoes recovered	75 80	300 24	1,000 6	2,000 1	5,000 1	43
5	*A. leucocelaenus & Haemagogus spegazzinii* (forest mosquitoes) [flight]	Kilometers from release point Mosquitoes recovered/100 man-hr	1.0 7	2.0 1	2.4 0.5	2.7 0.2	4.0 0.1	12
6	*A. polynesiensis* (mosquito) [flight]	Yards from release point Mosquitoes recovered	0 37	50 8	100 3	150 0		41
7	*Agriotes obscurus* (click beetle) [walking, running]	Feet from release point Beetles/trap	3 12	9 3	18 0.6	36 0.1		79
8	*Anastatus bifasciatus* (gypsy moth egg parasite) [flight]	Yards from release point Eggs parasitized, % (north) Eggs parasitized, % (south)	100 23 32	900 12 20	1,500 9 18	3,900 4 13	5,100 3 12	16
9	*Anopheles funestrus* (mosquito) [flight]	Yards from riverbank Mosquitoes caught	100 179	600 14	1,200 5	2,400 4		20
10	*A. gambiae* (African malaria mosquito) [flight]	Miles from release point Mosquitoes recovered	0.75 3.0	1.25 2.2	1.75 1.6	2.25 1.2		20
11	*A. pseudopunctipennis* (mosquito) [flight]	Miles from release point Mosquitoes recovered	0-1 16	1-2 10	2-3 8	3-4 6		77
12	*A. quadrimaculatus* (malaria mosquito) [flight]	Feet from source Mosquitoes caught	500 71	1,500 43	2,500 30	3,500 22	6,500 6	81
13		Feet from mosquito source Malarial infections, %	500 36	1,500 22	3,500 11	6,000 4		8[illegible]
14		Miles from breeding-site reservoir Females caught/wk	0.5 542	1.5 79	2.5 5	3.5 3	4.5 1	27
15	*Anthonomus grandis* (boll weevil) [flight]	Yards from overwinter area Weevils trapped	220 59	440 43	880 26	1,320 17	1,760 9	32
16	*A. grandis* [crawling]	Feet from release point Females recovered Males recovered	25 17 28	75 8 6	125 3 2	175 0 1	225 0 0	75
17	*Apis mellifera* (honeybee) [flight]	Yards from apiary Honeybees found	5.5 6.1	11 3.9	16.5 2.6	22 1.6	33 0.3	26

continued

114. DISPERSION OF SMALL ORGANISMS

Part I. INVERTEBRATES

	Invertebrate (Common Name) [Means of Dispersion]	Distances and Units Dispersed						Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Horizontal Dispersion							
18	*Apis mellifera* (honeybee) [flight]	Yards from apiary Pollination/2 sq yd	200 8	500 7	833 7	1,126 6	1,426 6	57
19		Feet from apiary Honeybees/2 sq yd Yield of red clover seed, lb/2 sq yd	130 21 65	630 13 34	1,130 9 22	1,730 7 14	2,330 5 8	6
20	*Bruchus pisorum* (pea weevil) [flight]	Feet from field margin Weevils found	300 51	600 50	1,400 48			51
21		Miles from overwinter area Weevils found	1 13	2 8	3 5	4 3	5 2	90
22	*Calendra maidis* (maize billbug) [crawling]	Rows from field margin Beetles found	3 19	9 11	33 3	50 1		11
23	*Camnula pellucida* (clear-winged grasshopper) & *Melanoplus mexicanus* (migratory grasshopper) [crawling[1]]	Yards from release point Grasshoppers recovered	10 179	50 85	90 51	160 18		78
24	*Carpocapsa pomonella* (codling moth) [flight]	Feet from release point Moths recovered, %	75 57	189 25	264 13	332 5		87
25	*Catocala* spp. (moth) [flight]	Feet from release point Moths recovered	13 8.1	88 3.7	163 2.4	238 1.5	363 0.6	7
26	*Chalcodermus aeneus* (cowpea curculio) [unknown]	Feet from field margin Curculios found	1.0 1.49	11.5 0.71	37.5 0.40	105.0 0.14	138.5 0.07	4
27	*Chionaspis furfura* (scurfy scale) [crawling]	Inches from dispersal point Mature scales recovered	1.5 44	7.5 7	13.5 3	19.5 0.7	22.5 0.1	39
28	*Circulifer tenellus* (beet leafhopper) [flight]	Miles from breeding area Leafhoppers caught	15 499	35 151	52 76	105 15	215 4	31
29	*Cochliomyia hominivorax* (screwworm) [crawling]	Inches from carcass Larvae/sq ft	3 320	9 47	15 4	21 2		86
30	*C. macellaria* (secondary screwworm) [flight]	Miles from release point (rural) Flies recovered	0.5 2.2	2.5 0.2	4.5 0.1	6.5 0.1	9.0 0.1	70
31	*C. macellaria*[2] [flight]	Miles from release point Traps containing flies, %	0.25 70	1 56	2 42	3 34		69
32	*Conotrachelus nenuphar* (plum curculio) [flight]	Feet from release point Curculios recovered	50 48	136 13	235 5	335 2	478 1	83
33	*Culex quinquefasciatus* (southern house mosquito) [flight]	Miles from release point Mosquitoes recovered	0.2 47	0.5 3	0.75 2	1.0 5	2.5 1	74
34	*C. tarsalis* (mosquito) [flight]	Miles from release point Mosquitoes recovered	0.25 13	0.75 12	1.25 2	1.75 0	2.5 1	74
35	*Culicoides grahamii* (punkie) [flight]	Yards from edge of breeding site Punkies caught biting	5 20	25 12	50 9	100 6	150 4	62
36	*C. impunctatus* (punkie) [flight]	Yards from breeding center Males caught Females caught	0 1,163 832	28 311 258	57 130 135	80 43 77	89 16 58	47,48
37	*Cylas formicarius elegantulus* (sweet potato weevil) [flight]	Yards from source Sweet potato plants infested, %	440 42	880 32	940 31	1,320 26	1,760 21	14
38	*Daphnia pulex* (water flea) [crawling]	Inches from source Fleas found	0.5 21	2.5 9	4.5 5	6.5 2	8.5 0	8
39	*Dendroctonus monticolae* (mountain pine beetle) [flight]	Yards from road Trees killed, %	2 63	5 26	10 10	15 1		3
40	*D. valens* (red turpentine beetle) [flight]	Feet from source logs Infestation	50 63	200 27	400 9			36
41	*Diabrotica duodecimpunctata* (spotted cucumber beetle) [flight]	Feet from field margin Beetles found	11.5 0.32	37.5 0.27	105.0 0.22	138.0 0.20	273.0 0.17	4
42	*D. vittata* (striped cucumber beetle) [flight]	Miles from release point Beetles recovered	0.25 31	0.75 11	1.25 4	1.75 1		25
43	*Dissosteira longipennis* (high plains grasshopper) & *Melanoplus mexicanus* (migratory grasshopper) [flight]	Miles from release point Grasshoppers recovered	25 8	75 6	125 6	175 5	225 5	93
44	*Drosophila funebris* (fruit fly) [flight]	Meters from release point Flies recovered	5 17.1	25 1.7	45 0.5	65 0	75 0.1	85

/1/ Some flight by adults. /2/ Yellow-eyed mutant strain.

continued

114. DISPERSION OF SMALL ORGANISMS

Part I. INVERTEBRATES

	Invertebrate (Common Name) [Means of Dispersion]	Distances and Units Dispersed						Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Horizontal Dispersion							
45	*Drosophila melanogaster* (fruit fly) [flight]	Meters from release point Flies recovered	5 12.7	15 5.7	25 2.1	35 0.7	45 0.3	85
46	*D. repleta* (fruit fly) [flight]	Feet from release point Flies recovered	25 30	150 6	250 2	350 1	450 0	67
47	*Empoasca fabae* (potato leafhopper) [flight]	Miles from nearest land Leafhoppers caught	3 38	6 27	9 21	10 20		82
48	*Epitrix cucumeris* (potato flea beetle) [flight]	Feet from field margin Injuries/tuber	100 9	200 8	300 7	400 7	500 6	94
49	*Glossina* sp. (tsetse fly) [flight]	Miles from release point Males recovered	0 593	0.67 208	1.33 136	2.67 51	3.33 3	42
50		Yards from thicket to host animals Flies caught during dry season	25 52	50 13	100 7	125 2		58
51		Yards from thicket to host animals Flies caught during wet season	80 35	180 14	230 8	280 3		58
52		Miles from fly belt Compounds ruined, %	0.13 83	0.63 40	1.3 29	3.0 17	4.0 13	59
53	*G. morsitans* (tsetse fly) [flight]	Yards (following man) Flies found	50 30	1,000 13	2,000 9	4,000 5	6,000 3	84
54	*Grapholitha molesta* (oriental fruit moth) [flight]	Feet from orchard Moths caught	100 194	1,320 14	2,640 8			30
55	*Harmolita grandis* (wheat strawworm), spring form [crawling]	Feet from wheat stubble Infestation, %	10 4.2	20 3.0	30 2.1	40 1.4	60 0.5	50
56	*H. grandis*, summer form [flight]	Feet from wheat stubble Infestation, %	1 52	50 19	100 13	150 10		50
57	*H. tritici* (wheat jointworm) [flight]	Yards from wheat stubble Adults caught	58 18	174 9	290 4	450 0		13
58	*Heliothis armigera* (corn earworm) [flight]	Rows from light traps (convergence) Plants infested, %	1 32.4	3 31.9	5 31.6	10 31.3		10
59	*Hippodamia convergens* (convergent lady beetle) [flight]	Miles from release point Beetles recovered	0.5 1.1	1.5 0.6	2.5 0.4	3.5 0.3	5.5 0.1	18
60	*Hylurgopinus rufipes* (elm bark beetle) [flight]	Feet from source Beetles/sq ft	60 14	120 9	320 5	579 2	816 1	96
61	*Laemophloeus minutum* (flat grain beetle) [flight]	Feet from probable source Beetles caught	50 11	100 8	200 6	400 3		24
62	*Liriomyza pusilla* (serpentine leaf miner) [flight]	Feet from field margins Mines/leaf	20 76	100 64	140 50	180 31	260 17	95
63		Feet from field margins Potato yield, bushels/acre	9 171	100 188	300 202	400 206	600 211	95
64	*Littorina* sp. (periwinkle) [crawling]	Inches from release point Periwinkles found	0.5 20	1.5 9.5	3.5 3.0	4.5 2.0	5.5 1.0	8
65	*Lydella stabulans grisescens* (tachinid fly) [flight]	Miles from release point European corn borers parasitized, %	0.5 27	1.5 18	2.5 13	4.0 9	6.0 5	2
66	*L. stabulans grisescens* [flight[3]]	Miles from colonization point European corn borer larvae parasitized, %	0.5 25	2 16	4 12	6 9		55
67	*Macrosteles divisus* (six-spotted leafhopper) [flight, crawling]	Feet from release point Leafhoppers recovered	50 9	100 3	150 1	200 1		54
68		Feet from release point Days to first leafhopper recovery	30 4	225 13	450 16			54
69	*M. divisus* [flight]	Miles from nearest land Leafhoppers caught	3 516	6 145	9 37	10 18		82
70	*Melanoplus* spp.[4] (grasshopper) [crawling]	Feet from release point Grasshoppers on bare ground	100 17	200 10	300 6	400 3		60
71	*Merodon equestris* (narcissus bulb fly) [flight]	Feet from old planting Plants infested, %	7 42	85 21	150 16	200 13	300 10	23
72	*Musca domestica* (housefly) [flight]	Yards from release point Flies recovered	35 572	110 189	220 49	330 28		97
73		Miles from release point Tagged flies/trap	0.43 106	1.5 12	2.5 3	3.5 2	4.5 0.3	71
74	*Myzus persicae* (green peach aphid) [flight]	Rows from field margin Aphids/100 late potato leaves	10 3,076	20 1,700	40 1,009	80 661	160 484	49

/3/ Except for passive transportation by other insects. /4/ *See also* lines 23 and 43.

continued

114. DISPERSION OF SMALL ORGANISMS

Part I. INVERTEBRATES

	Invertebrate (Common Name) [Means of Dispersion]	Distances and Units Dispersed						Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Horizontal Dispersion							
75	*Pectinophora gossypiella* (pink bollworm) [flight]	Feet from moth source	1,000	2,750	3,500	6,250		63
		Worms/boll	1.33	1.22	1.20	1.16		
76	*Phaenicia* sp. (blowfly) [flight]	Miles from release point	0.25	0.5	0.75	1	1.25	80
		Flies recovered	31	11	5	2	0.5	
77	*P. sericata* (greenbottle fly) [flight]	Miles from release point	0.5	1	2	4	6	53
		Flies recovered, %	1.8	1.3	0.3	0.1	0	
78	*Phormia regina* (black blowfly) [flight]	Miles from release point	0.8	1.4	2.4	3.4	4.4	80
		Flies recovered	1.8	1.3	0.8	0.5	0.3	
79		Miles from release point	0.25	0.5	0.75	1.13		80
		Flies recovered	0.12	0.02	0.03	0		
80		Miles from release point	0.5	2	4	7	12	53
		Flies recovered, %	9.1	0.8	0.1	0	0	
81	*Phytophaga destructor* (Hessian fly) [flight]	Feet from wheat field	100	400	600			56
		Flies caught	95	16	12			
82		Feet from hibernation	7.5	27.5	47.5	97.5		46
		Plants infested, %	44	16	9	3		
83	*Popillia japonica* (Japanese beetle) [crawling]	Inches from release point	22	42	62	84		37
		Larvae recovered	79	44	23	7		
84	*P. japonica* [flight]	Feet from field margin	0	38.5	73.5	118.5		99
		Damage to corn, %	3.4	0.8	0.4	0		
85	*Porthetria dispar* (gypsy moth) [flight]	Feet from source	330	660	1,320	2,640		15
		Males caught	67	22	5	3		
86	*P. dispar* [carried by wind]	Feet from source	50	150	250	350	600	[illegible]
		Larvae found	16	4.4	1.7	1.3	0.5	
87	*Psila rosae* (carrot rust fly) [flight]	Yards inside field	1	5	15	30	50	100
		Larval mines/100 carrots	78	48	28	15	6	
88	*P. rosae* [burrowing in soil]	Yards from plants	15	25	35	45		65
		Pupae found	94	42	15	0		
89	*Psorophora* sp. (rice-field mosquito) [flight]	Miles from release point	0.5	2.5	4.5	6.5		72
		Mosquitoes recovered	8	0.6	0.2	0.1		
90	*P. confinnis* (rice-field mosquito) [flight]	Miles from release point	0.5	2.5	4.5	8.5	11.5	40
		Mosquitoes/trap	3.7	1.8	1.1	0.4	0	
91	*Pyrausta nubilalis* (European corn borer) [flight]	Rows from light trap convergence	1	2	3	4	5	38
		Plants infested, %	85	62	51	41	36	
92	*P. nubilalis* [crawling]	Inches from source	40	56	80	89	103	61
		Larvae found	56	34	13	7	0	
93	*Rhabdocnemis obscura* (New Guinea sugarcane weevil) [flight, crawling]	Feet from release point	265	405	600	740	825	88
		Weevils recovered	26	16	8	4	1	
		Days to recovery	52	60	70	76	78	
94	*Rhagoletis pomonella* (apple maggot) [flight]	Feet from release point	37.5	87.5	137.5	187.5	237.5	66
		Maggots recovered	47	33	26	21	17	
95	*Saissetia oleae* (black scale) [air currents]	Feet from source	13	35	100	250	450	73
		Scales caught	564	433	293	172	92	
96	*Scolytus multistriatus* (smaller European elm bark beetle) [flight]	Feet from source	50	100	200	400	1,000	87
		Twig crotches wounded, %	39	23	14	8	3	
97	*Simulium* sp. (blackfly) [flight]	Miles from release point	0.5	2.5	4.5	9.5	10.5	17
		Flies recovered/visit	2.3	0.4	0.1	0.1	0	
98		Days between release and recovery	5	25	45	65		17
		Flies caught	30	0	1	2		
99	*Sitophilus oryza* (rice weevil) [probably crawling]	Feet from source	50	100	200			24
		Weevils found	3	2	1			
100	*Tiphia vernalis* (Japanese beetle parasite) [flight]	Feet from feeding area	7	21	49	77	90	34
		Eggs/larva	3.7	3.2	2.7	2.5	2.4	
101	*Trioza tripunctata* (blackberry psyllid) [crawling]	Rows from field margin	1	3	5	10	20	64
		Psyllids/10 bushes	10	5	4	3	1	
102	*Tyloderma fragariae* (strawberry crown borer) [crawling]	Yards from release point	25	50	68	125	300	76
		Borers recovered	6	6	5	4	1	
	Vertical Dispersion							
103	*Anopheles* spp. (mosquito) [flight]	Altitude, meters (in forest)	0	[illegible]	10	15		19
	A. darlingi	Distribution, %	51	18	19	12		
	A. mediopunctatus	Distribution, %	3	3	39	55		
	A. shannoni	Distribution, %	4	7.3	24.6	64.1		

continued

114. DISPERSION OF SMALL ORGANISMS

Part I. INVERTEBRATES

	Invertebrate (Common Name) [Means of Dispersion]	Distances and Units Dispersed						Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Vertical Dispersion							
104	*Anopheles quadrimaculatus* (malaria mosquito) [flight]	Altitude, feet Mosquitoes caught	1.5 14	3.0 11	6.0 5	7.5 3		28
105	Aphididae (aphid) [flight]	Altitude, feet Aphids caught	50 270	250 228	500 75	1,000 21	1,500 6	44
106	Aphididae [air currents, flight]	Altitude, miles Aphids caught	0.17 2	1.15 9	2.17 16	2.68 19		68
107	Aphididae, 7-hr collection [flight]	Altitude, feet Aphids caught/hr	10 18	150 3	500 2	1,000 1		45
108	*Circulifer tenellus* (beet leafhopper) [flight]	Altitude, feet Leafhoppers caught	8 276	16 211	25 169			21
109		Altitude, feet Parasitism, %	2.5 3.5	15 1.7	32 0.9			52
110	Coccinellidae (ladybird beetle) [flight]	Altitude, miles Beetles caught	0.17 40	1.15 13	2.17 4	2.68 1		68
111	*Drosophila* sp. (fruit fly) [flight]	Altitude, miles Flies caught	0.54 413	2.04 237	3.54 164	5.04 117		68
112	*Epitrix hirtipennis* (tobacco flea beetle) [flight]	Altitude, feet Beetles caught	12 96	19 41	23 18			1
113		Altitude, feet Beetles caught/day	1.5 56	5 32	14 12	19 6	23 2	22
114	*Heterodera rostochiensis* (golden nematode of potato) [wind currents]	Height of trap, inches Viable cysts	22 2,077	38 435	55 103			92
115	Insects, miscellaneous [flight, air currents]	Altitude, feet Insects caught/cu ft air	10 239	177 51	277 21			29
116		Altitude, feet Insects caught/10 min flight	20 26	1,000 6	4,000 3	7,000 1		35
117	*Psallus seriatus* (cotton fleahopper) [flight, air currents]	Altitude, feet Fleahoppers caught	5.5 61	11.5 97	17.5 156	23.5 250		22
118	*Pyrausta nubilalis* (European corn borer) [flight]	Altitude, feet Moths caught	5 914	10 547	15 332			33

Contributor: Wolfenbarger, D. O.

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Part I. INVERTEBRATES

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continued

114. DISPERSION OF SMALL ORGANISMS

Part II. VIRUSES, BACTERIA, AND FUNGI

	Disease (Organism) [Means of Dispersion]	Distances and Units Dispersed						Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Horizontal Dispersion							
	Viruses							
1	Beet mosaic [black bean aphid]	Yards from steckling bed	220	1,320	1,560			31
		Plants infected, %	95	57	12			
2	Cabbage mosaic [cabbage aphid]	Miles from fields	0.06	0.6	7	22		30
		Plants infected, %	72.6	46.9	1.0	0.3		
3	Celery mosaic [insects]	Feet from harborer plants	3	15	28	75	120	43
		Diseased plants, %	100	89	52	28	16	
4	Cucumber cucurbit mosaic [insects]	Yards from harborer plant	1	140	225	350	500	7
		Days to first symptoms	17	42	45	47	49	
5	Eastern X-disease of peach [certain leafhoppers]	Feet from chokecherry plants	50	125	187.5			40
		Plants infected, %	89.3	8.1	0.6			
6	Mild streak of black raspberry [presumably insects]	Feet from wild brambles	25	75	125			16
		Infections, %	66	29	12			
7	Potato calico [insects]	Rows from source	1	2	3	4	5	29
		Diseased plants	26	27	22	17	13	
8	Potato leaf roll [insects]	Inches from inoculum source	18	36	54	72	90	11
		Plants infected	41	25	17	12	8	
9	Potato leaf roll [aphids]	Rows from infected plants	1	2	3	4	6	22
		Diseased plants, %	21	12	7	5	1	
10	Potato mosaic [insects]	Rows from diseased plants	1	2	3	4	6	21
		Diseased plants, %	36	24	18	13	6	
11	Potato yellow dwarf [six-spotted leafhopper]	Feet from old meadow	1	30	60	90	135	9
		Diseased plants, %	80	23	14	9	4	
12	Rugose mosaic of potato [insects]	Inches from inoculum source	18	36	54	72	90	11
		Infected plants	37.7	11.7	5.3	3.4	2.8	
13	Severe streak of raspberry [insects]	Rows from wild brambles	3	8	13	18	23	5
		Diseased plants	165	86	47	21	1	
14	Sudden death of clove [probably insects]	Tree intervals	1	2	3	4	5	24
		Life expectancy, months	30.2	38.1	42.7	46.0	48.5	
15	Sugar beet curly top [beet leafhopper]	Miles from breeding ground	57	265	315	385	430	33
		Diseased plants, %	100	15	10	4	1	
16	Tristeza disease of citrus [aphids]	Feet from inoculum source	5	25	45	65	73	1
		Diseased trees, %	51	29	20	15	13	
17	Wheat streak mosaic [eriophyd mite]	Yards from source	0	8	18	50	90	34
		Plants infected, %	64	26	19	10	5	
	Bacteria							
18	(Colonies on sea-water medium) [air currents]	Miles from land (over water)	5	80	275			46
		Bacterial colonies	41	58	65			
19		Miles from sea (over land)	0.	0.06	0.25	0.50	1.0	46
		Bacterial colonies	548	292	215	177	138	
	Fungi							
20	(Air-borne spores) [wind]	Degrees north of equator	$57^{\circ}30'$	$64^{\circ}20'$	$68^{\circ}55'$	$71^{\circ}5'$		27
		Fungus colonies on plate	3.61	0.49	0.48	0.72		
21	Beet downy mildew *(Peronospora* sp.) [wind]	Meters from seed plants	10	150	1,000			13
		Plants injured, %	28	8	1			
22	Blossom infection *(Sclerotinia laxa)* [air currents]	Feet from center of nearest source row	22	44	66	88		44
		Blossom infection, %	55.7	39.1	29.3	22.4		
23	*(Bovista plumbea)* [air currents]	Meters from release point	5	10	15	20		39
		Spores caught	912	323	165	102		
24	Cedar and apple rust *(Gymnosporangium* sp.) [air currents]	Yards from infected trees	0	55	110	220	440	18
		Leaf infections	64	40	33	26	19	
25	Chestnut blight *(Endothia parasitica)* [air currents]	Feet from spore source	27	85	180	266		12
		Ascospores found	23	11	8	8		
26	Crown rust of oats *(Puccinia coronata)* [wind]	Feet from inoculum source	3	5	7.7	10.3	13	45
		Infections, %	92.9	53.4	35	19.5	0.7	
27	Damping-off disease [mycelial growth]	Centimeters from inoculum source	1	3	5	7	9	2
		Plants damped-off, %	100	8	7	16	0	
28	Downy mildew *(Pseudoperonospora humilis)* [air currents]	Feet from spore source	10	50	100	200	400	20
		Leaves infected, %	26	16	12	7	3	

continued

Part II. VIRUSES, BACTERIA, AND FUNGI

	Disease (Organism) [Means of Dispersion]	Distances and Units Dispersed						Ref-er-ence
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
		Horizontal Dispersion						
	Fungi							
29	Dutch elm disease *(Ceratostomella ulmi)* [elm bark beetles]	Feet from inoculum source Diseased trees/acre	200 2.52	600 0.38	1,000 0.47	1,800 0	2,300 0.09	19
30		Feet from inoculum source Diseased trees	12.5 27	62.5 19	300 11	575 8		4
31	Eyespot disease of wheat *(Helminthosporium sacchari)* [water]	Meters from spore source Culms with eye spots, %	5 26.7	20 12.3	50 7.7	70 6.4		25
32	Hollyhock rust [gravity and ejection]	Spore dispersal, millimeters Spores/0.1 sq mm	0.15 14.6	0.35 7.6	0.55 2.2	0.75 0.1		3
33	Leaf spots on tulips [raindrop splash and wind]	Centimeters from conidia source Lesions/plant	15.2 31.6	34.6 20.1	58.0 12.9	79.8 8.5	102.0 5.1	42
34	Loose smut of wheat *(Ustilago tritici)* [air currents]	Meters from spore source Smutted heads	2 241	4 234	24 114	80 0		26
35	Maize rust *(Puccinia sorghi)* [wind]	Kilometers from spore source Plants attacked, %	0.5 100	2.5 3	4.5 0.3	6.5 0		47
36	Onion mildew *(Peronospora destructor)* [air currents]	Feet from onion sets Lesions/100 ft row	120 1,138	780 98	1,750 1	2,000 0		23
37	Potato late blight *(Phytophthora infestans)* [wind]	Centimeters from edge of infective group Plants infected, %	30 89	90 63	150 43	210 22	270 5	10
38	Powdery mildew on barley *(Erysiphe graminis)* [wind]	Meters from source Plants affected, %	1.5 99	3.5 84	5.5 76	7.5 70	8.5 68	28
39	Stem rust *(Puccinia graminis)* [wind]	Feet from barberry hedge Grass infected, %	15 100	125 41	225 5	325 1	425 0.5	17
40	Stem rust on rye *(P. graminis secalis)* [wind]	Meters from source plant Yield/100 ears, grams	50 47.6	300 92.3	1,000 122.3	3,000 149.7		8
41	*(Tilletia tritici)* [air currents]	Meters from release point Spores caught	5 800	10 168	15 49	20 30		39
42	Tobacco blue mold *(Peronospora tabacina)* [wind]	Yards from source Plant lesions/1,000 sq in. of field	0 140	4 8	8 1	12 0.5		41
43	Wheat stem rust *(Puccinia graminis)* [air currents]	Miles from known source Spores collected	200 13,092	360 10,768	580 8,883	740 7,920	940 6,975	37
44	White pine blister rust *(Cronartium ribicola)* [air currents]	Feet from gooseberry bush Diseased trees, %	50 75	150 55	350 40	450 36	650 29	36
		Vertical Dispersion						
45	(Bacteria, miscellaneous) [air currents]	Altitude, feet Bacteria	1,500 113	6,000 48	12,000 15	15,000 5		32
	Fungi							
46	Azalea flower spot *(Ovulinia azaleae)* [air currents, water drip]	Inches above ground Infections	4 42	10 28	18 17	48 0		35
47	Onion mildew *(Peronospora destructor)* [air currents]	Altitude, feet Spores/cu ft air	100 32	200 102	700 451	1,200 801		23
48	Wheat stem rust *(Puccinia graminis)* [air currents]	Feet above barberry bushes Aeciospores caught	1,000 19	2,000 14	7,000 5	12,000 1		38
49		Altitude, feet Uredospores	1,000 48,200	5,000 7,730	10,000 144	14,000 40		6
50		Elevation, meters Spores/sq cm/min	30 1,458	400 490	600 339	800 231		15

Contributor: Wolfenbarger, D. O.

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114. DISPERSION OF SMALL ORGANISMS

Part II. VIRUSES, BACTERIA, AND FUNGI

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Part III. POLLEN AND SEEDS

	Spermatophyte (Common Name) [Means of Dispersion]	Distances and Units Dispersed						Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Horizontal Dispersion							
1	*Abies alba* (silver fir) [air currents]	Yards from seed trees Seedlings/acre	55 22	165 9	275 3			19
2	*Agropyron cristatum* (crested wheatgrass) [wind]	Rods from field Pollen grains	5 72	15 29	25 10			23
3	*A. intermedium* (intermediate wheatgrass) [wind]	Rods from field Pollen grains	5 44	12 17	25 4			23
4	*Beta* sp. (beet) [wind]	Meters from seed fields Pollen grains/sq cm	0 11,613	300 1,941	500 1,075	800 278		21
5		Feet from contaminant Hybrids, %	2.3 5.6	20.7 0.3	43.2 0.2	73.2 0		5
6	*Brassica rapa* (turnip) [insects]	Feet from contaminating plants Proportion of hybrid seed, %	1 42	4.5 14	15 2.5	30 0.2	42.5 0.5	6
7	*Bromus* sp. (bromegrass) [wind]	Rods from field Pollen grains	5 146	15 41	25 21	40 10	60 4	23
8	*Cedrus atlantica* (atlas cedar) [wind]	Feet from source tree Pollen grains	40 189	120 116	240 71	325 51	700 0.1	37
9	*C. libani* (cedar of Lebanon) [wind]	Feet from source tree Pollen grains	15 127	75 62	135 37	195 22		37
10	*Citrullus vulgaris* (watermelon) [honeybees]	Feet from field margin Melons/acre	50 734	250 653	450 623	650 605		28

continued

114. DISPERSION OF SMALL ORGANISMS

Part III. POLLEN AND SEEDS

	Spermatophyte (Common Name) [Means of Dispersion]	Distances and Units Dispersed						Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
		Horizontal Dispersion						
11	*Dactylis* sp. (orchard grass) [wind]	Meters from field Pollen grains/sq cm	0 3,096	200 447	400 172	600 120	800 86	21
12	*Fraxinus* sp. (ash) [wind]	Feet from source tree Pollen grains	25 2,545	50 1,008	150 141	400 29		37
13	*Gilia* sp. (gilia) [insects]	Feet from white flowers Hybridization of blue-flowered plants, frequency	25 100	250 74	2,640 44	10,560 26		12
14	*Gossypium* sp. (cotton) [wind]	Feet from marker plants Natural crossing, %	7.5 29.7	20.0 8.5	32.5 9.1	45.0 5.1	70.0 0.8	1
15		Feet from red cotton Hybrids, %	16 6.9	35 3.0	51 2.0	99 0.9	189 0.3	15
16	*G. arboreum* (Asiatic tree cotton) [bumblebees]	Feet from flowers dusted with methylene blue Flowers with dye particles, %	1.5 60	4.5 49	7.5 44	10.5 40	13.5 38	33
17	*G. hirsutum* (upland cotton) [bumblebees]	Feet from flowers dusted with methylene blue Flowers with dye particles, %	1.5 94	4.5 85	7.5 81	10.5 78	13.5 76	33
18	*G. hirsutum* [wind or insects]	Feet from contaminant Cross-pollination, %	1 18	10 12	100 7	700 3	1,800 1	29
19	*Helianthus* sp. (sunflower) [honeybees]	Feet from apiary Seed yield, lbs/acre	0 1,285	200 981	600 918	1,000 889		13
20	*Juglans regia* (Persian walnut) [air currents]	Feet from pollen source Pollen grains/sq mm/24 hr	60 4	150 2.8	500 1.4	1,000 0.6	1,600 0	9
21	*Juniperus scopularum* (western red cedar) [air currents]	Yards from seed source Seedlings/acre	22 5,588	44 259	66 192	88 0		19
22	*Leontodon* sp. (hawkbit) [wind]	Feet from source Seeds	2 184	12 21	20 9	28 3.5	32 1	7
23	*Lolium* sp. (ryegrass) [wind]	Meters from ryegrass field Pollen grains/sq cm	0 4,045	200 1,053	500 535	700 345	900 204	21
24	*L. perenne* (perennial ryegrass) [wind]	Centimeters from rough clone contaminant Rough plants, %	40 40.1	120 13.8	200 7.2	280 3.8		34
25	*Lycopersicon esculentum* (tomato) [air currents; insects ?]	Feet from contaminant Cross-pollination, %	6 1.1	18 0.6	30 0.4	42 0.2	54 0.1	11
26	*Malus pumila* (common apple) [wind]	Feet from source tree Pollen grains	0 13	165 2	330 0.9			37
27		Feet from pollen source Fruit set/100 blossom spurs	8 52	19 34	42 18			30
28	*M. pumila* [honeybees]	Yards from bee colonies Fruit set, %	25 7	50 7	75 6	100 6	150 4	20
29	*Oryza sativa* (rice) [dehiscence and wind]	Centimeters from pollen source Pollen grains	25 22	50 9	100 3	150 1	200 0.4	31
30	*Panicum virgatum* (switch grass) [wind]	Rods from field Switchgrass pollen	5 27	15 7	25 4	40 2	60 0.5	23
31	*Parthenium argentatum* (guayule parthenium) [wind]	Yards from guayule plants Pollen grains/sq in.	100 89	400 49	850 27	1,200 17		14
32	*Paspalum notatum* (Pensacola Bahia grass) [wind]	Rods from albino seedling isolation blocks Albinos, %	0 14.0	5 19.3	10 21.7	15 23.0		18
33	*Pennisetum glaucum* (pearl millet) [wind]	Yards from release point Pollen, %	4 100.0	50 8.9	200 0.8	400 0.4		18
34	*Persea* sp. (persea) [honeybees]	Feet from apiary Fruit yield/tree, bushels	125 2.38	562.5 1.26	1,062.5 0.94			36
35	*P. americana*, Taylor variety (American avocado) [insects]	Rows from nearest reciprocating variety Fruit set/tree	1 61	2 54	3 50	4 47	5 44	35
36	*Phaseolus limensis* (lima bean) [insects]	Feet from pollen parent Natural hybrids, %	2.5 7.3	5.0 2.7	7.5 1.4	12.5 0.6	32.5 0.5	2
37	*P. lunatus* (sieva bean) [air currents; insects?]	Yards from kidney beans Cross-pollination, %	1 5	2 4	3 3	5 2	9 1	4
38	*P. vulgaris* (kidney bean) [air currents; insects?]	Yards from sieva beans Cross-pollination, %	1 9	2 7	3 6	5 4	9 3	4

continued

114. DISPERSION OF SMALL ORGANISMS

Part III. POLLEN AND SEEDS

	Spermatophyte (Common Name) [Means of Dispersion]	Distances and Units Dispersed						Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
		Horizontal Dispersion						
39	*Phleum pratense* (timothy) [wind]	Meters from timothy field Pollen grains/sq cm	0 2,613	100 781	200 505	300 343	500 140	21
40	*Picea* sp. (spruce) [wind]	Feet from source tree Pollen grains	0 9.7	165 0.1	330 0.7			37
41	*P. mariana* (black spruce) [air currents]	Feet from seed trees Seedlings/acre	10 71,260	60 47,180	160 18,540	240 0		3
42	*Pinus* spp. (pine) [air currents]	Yards from seed tree stand Seedlings/acre	3,344 2,002	6,248 991	8,426 507			24
43	*P. cembroides* (Mexican piñon pine) [wind]	Feet from source tree Pollen grains	10 8,479	75 462	150 86	225 38	300 52	37
44	*P. echinata* (shortleaf pine)	Miles from forest margin Pollen, %	0 100	0.1 17	0.2 15	0.25 10		8
45	*P. monticola* (western white pine) [air currents]	Yards from seed source Seedlings/acre	22 616	44 177	66 57	88 9		19
46	*Populus* sp. (poplar) [wind]	Feet from source tree Pollen grains	50 107	500 86	1,400 76	3,200 69	4,200 66	37
47	*P. deltoides* (eastern poplar) [wind]	Feet from source tree Pollen grains	25 115	250 62	500 46	1,550 20	3,550 0.3	37
48	*Pseudotsuga taxifolia* (Douglas fir) [air currents]	Feet from seed trees Seedlings/acre	2 304	4 170	6 91	8 35		19
49	*Raphanus* sp. (radish) [insects]	Feet from contaminant Contamination, %	1 11.9	3 5.3	4.2 1.7	5.0 1.6	6.4 0.7	6
50	*R. sativus* (garden radish) [wind or insects]	Feet from contaminant Cross-pollination, %	1 75	95 18	191 10	335 3	420 0	10
51	*Secale cereale* (rye) [wind]	Rods from rye field Pollen grains	5 453	15 232	25 124	40 52	60 11	23
52		Meters from rye field Pollen grains/	100 4,181	300 2,579	500 1,834	700 1,343		21
53	*S. cereale* [air currents]	Feet from polle Cross-pollinatio.	0.3 24	2.6 18	5.2 13	7.9 9	10.5 7	32
54	*Trifolium hybridum* (alsike clover) [honeybee]	Yards from bee colonies Seeds/head	5.5 38	440 33	880 32			26
55		Miles from bee yards Seed yield, lbs/acre	0.125 128	0.625 95	1.5 77	2.5 67		16
56	*T. pratense* (red clover) [honeybees]	Yards from apiary Seed yield, lbs/acre	200 166	500 149	833 139	1,126 133	1,426 128	25
57	*T. repens* (white clover) [honeybees]	Miles from bee yards Seed yield, lbs/acre	0.125 206	0.625 102	1.5 46	2.5 13		16
58	*Tsuga heterophylla* (western hemlock) [air currents]	Yards from seed trees Seedlings/acre	22 1,434	44 169	66 101	88 0		19
59	*Ulmus* sp. (elm) [wind]	Feet from source tree Pollen grains	500 115	1,100 152	2,700 12	5,500 8		37
60	*Zea mays* (corn) [wind]	Rods from field Pollen grains	5 18	15 6	25 3	40 2	60 0.8	23
61		Feet from pollen source Pollen grains	10 7,330	30 341	50 121	70 30		5
62		Feet from pollen source Seed set	4 256	16 197	28 122	40 75	44 31	17
63		Feet from contaminating plants Hybridization, %	13 7	29 6	45 3	61 1.3	77 0.3	5
64		Rods north of contaminating field Outcrossed seeds, %	5 16.5	25 0.8	60 0.2	100 0.2		22
		Vertical Dispersion						
65	*Beta vulgaris* (beet) [air currents]	Altitude, feet Pollen grains	1,000 56	2,000 26	3,000 14	4,000 9		27

Contributor: Wolfenbarger, D. O.

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115. EFFECT OF TEMPERATURE ON INACTIVATION AND SURVIVAL: VIRUSES

Part I. ANIMAL VIRUSES

	Virus	Substrate	Inactivation Temp. °C	Inactivation Time min	Reference
	(A)	(B)	(C)	(D)	(E)
1	Adenovirus		56	2.5-5.0	17
2			56	30	10
3	Common cold		56	30	2,3
4	Coxsackie A		53-55	30	4
5	Coxsackie C	Aqueous suspension	60	30	17
6		Milk, cream	70-80	30	17
7		Tissue suspension[1]	55	30	5
8		Water	60	30	13
9	Dengue		50	30	21
10	Distemper, canine		58	20	20
11			60	30	15
12	Encephalitis, western equine	Filtrate	56	30	8
13			60	10	17
14	Foot-and-mouth disease	Defibrinated blood	55	20	16
15		Epithelium suspension[2]	85	360	6
16		Vesicular fluid	60	5	16
17	Fowl plague		55	30	15
18	Herpes simplex	Aqueous suspension	52	30	12
19		Moist	52	30	3
20		Dry	90	30	3
21	Hog cholera		60-70	60	19
22	Infectious hepatitis		56	30	17
23			60	60	
24	Influenza A	Allantoic preparation	55	5-15	9
25			56	30[3]	3
26			67	30	1
27	Influenza B	Allantoic preparation	56	15-30	9
28	Louping ill		56	30	7
29		Tissue suspension[1]	58	10	17
30			60	2	17
31			80	0.5	17
32	Lymphogranuloma venereum		56	10	17
33	Measles		55	15	19
34			56	60	12
35	Mumps		55	20	17
36			56	20	3

/1/ Mouse brain. /2/ Cattle tongue. /3/ Some strains 90 minutes.

continued

115. EFFECT OF TEMPERATURE ON INACTIVATION AND SURVIVAL: VIRUSES

Part I. ANIMAL VIRUSES

	Virus	Substrate	Inactivation Temp. °C	Inactivation Time min	Reference
	(A)	(B)	(C)	(D)	(E)
37	Newcastle disease		56	5[4]	1
38			56	120	14
39	Poliomyelitis	Aqueous suspension	45-55	30	18
40			50-55	30	12
41		Milk, cream, ice cream	62	30	17
42		Milk	61.7	30	11
43			71.1	0.25	
44		Tissue suspension[1]	55	30	5
45		Water	50-55	30	11
46			75	30	3
47	Psittacosis		60	10	17
48	Rabies		50	60	3,12
49			56	30	19
50	Rabies		60	5	3,12
51			100	2-3	3
52		Aqueous suspension	54-60	60	17
53		Dry	54-56	1,440	17
54	Rift Valley fever	Blood	56	40	20
55	Small pox		55	30	17
56		Moist heat	60	10	3
57		Dry heat	100	10	3
58	Vaccinia	Dry	100	10	17
59		Fluid suspension	60	10	
60	Trachoma		45	15	17
61	Yellow fever		55	5	19
62			65	10	12

/1/ Mouse brain. /4/ Some strains 360 minutes.

Contributors: (a) Dupre, Margaret V., (b) Frobisher, Martin

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Part II. PLANT VIRUSES

Medium (column D): dil. = diluted. **Inactivation** (column G): Temperature at which infectivity is lost in 10 minutes.

	Virus	Plant Source of Virus	Species	Test Conditions: Medium	Test Conditions: Temp., °C	Survival Time	Inactivation, °C	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
1	Alfalfa mosaic	*Cucumis sativus*	*Nicotiana tabacum*	Dry tissue[1]	1-2	>303 da		44
2		*Nicotiana tabacum*[2]	*Phaseolus vulgaris* (Early Golden Cluster)	Plant juice	4	>7 da		56
3				Phosphate buffer[3]	24	>4 da		

/1/ Desiccated above freezing temperature. /2/ Necrotic type, young. /3/ Purified virus in 0.1 *M* phosphate buffer.

continued

115. EFFECT OF TEMPERATURE ON INACTIVATION AND SURVIVAL: VIRUSES

Part II. PLANT VIRUSES

	Virus	Plant Source of Virus	Species	Test Conditions: Medium	Test Conditions: Temp., °C	Survival Time	Inactivation, °C	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
4	Alfalfa mosaic	*Pisum sativum* & *Vicia faba*	*Phaseolus vulgaris* (Stringless Green Refugee)	Plant juice	20 (dark)	<5 da	70	76
5	Dolichos lablab strain	*Vicia faba minor*	*V. faba minor*	Plant juice	25	>24-<48 hr	65-71	51
6				Crushed dried leaves	Room	>3 mo		
7	Israel strain	*Nicotiana glutinosa*	*Phaseolus vulgaris bulgarit*	Plant juice dil. 1:1[4]	10-15	4 hr		47
8	Pierce strain	*Medicago sativa*	*Phaseolus vulgaris* (Stringless Green Refugee)	Plant juice	Room ?	9 da	64	53
9	Vein necrosis strain	*Glycine soja*	*Phaseolus vulgaris* (Pinto U.I. 111)	Plant juice	18	>30-<32 hr	62-64	78
10		*Phaseolus vulgaris*	*P. vulgaris* (Pinto U.I. 111)	Dry tissue	Room	>50-<95 da		78
11	Common bean mosaic	*Phaseolus vulgaris*	*P. vulgaris* (Stringless Green Refugee)	Plant juice	18	>28-<32 hr	56-58	53
12	Southern bean mosaic	*Phaseolus vulgaris*	*P. vulgaris* (Pinto U.I. 111)	Plant juice	18	32 wk	90-95	77
13	Bean-pod mottle	*Phaseolus vulgaris*	*P. vulgaris* (Pinto U.I. 111)	Plant juice	18	>62-<93 da	70-75	79
14	Bean yellow mosaic	*Phaseolus vulgaris*	*P. vulgaris* (Stringless Green Refugee)	Plant juice	18	>24-<32	58-60	81
15	Bean yellow stipple	*Phaseolus vulgaris*	*P. vulgaris* (Pinto U.I. 111)	Plant juice	18	5 da	72-75	80
16	Cucumber mosaic	*Cucumis sativus*		Plant juice	Room	<22 da	60-70	17
17				Dry tissue	Room	>40 da		
18		*Nicotiana glutinosa*	*Chenopodium amaranticotor*	Plant juice	10-15	6 da		47
19			*N. tabacum*	Plant juice[5]	26-32	>3 da	>60-<65	35
20		*Nicotiana tabacum*	*N. tabacum*	Plant juice[5]	26-32	>1-<2 da	>65-<70	35
21		*Zea mays*	*Nicotiana tabacum*	Leaf powder[1]	1-2	>669 da		44
22			*Z. mays*, *Nicotiana tabacum*	Leaf powder[8]	23 (over $CaCl_2$)	>58 da		44
23	Pea mosaic	*Pisum sativum*	*P. sativum* (Prince of Wales)	Plant juice	18	>48-<72 hr	60-64	22
24	Pea enation mosaic	*Pisum sativum*	*P. sativum* (Prince of Wales)	Plant juice	18	>72-<96 hr	56-58	72
25	Pea mottle	*Pisum sativum*		Plant juice	18	>24-<32 hr	56-58	81
26	Pea streak	*Pisum sativum*	*P. sativum* (Perfected Prince of Wales)	Plant juice	18	>16-<32 da	58-60	27
27	Pea stunt	*Pisum sativum*	*P. sativum* (Perfected Prince of Wales)	Plant juice	18	>48-<72 hr	58-60	26
28	Potato A	*Nicandra physalodes*[7]	*Solanum demissum*	Plant juice, undiluted	18	≤18 hr		45
29		*Nicotiana tabacum ?*	*N. tabacum ?*	Plant juice	Room	Few hours	ca. 50	28
30	Veinbanding strain	*Nicotiana tabacum ?*	*N. tabacum*	Plant juice	Room	4 da	>58-<60	39
31	Potato M	*Solanum tuberosum* (seedling EK)	*Datura metel*	Plant juice	20	>2-<4 da	65-70	2
32	Potato S	*Solanum tuberosum* (seedling 41956)	*Nicotiana debneyi*	Plant juice	20	>4-<8 da	>55-<60	2
33	Potato X	*Lycopersicon esculentum*	*Nicotiana tabacum* (Connecticut Havana) & *L. esculentum* (John Baer)	Leaves, air-dried	Room	50 da		13

/1/ Desiccated above freezing temperature. /4/ With water. /5/ Kept in a darkened drawer. /8/ Dried at 35°C. /7/ Inoculated 14 days before test.

continued

115. EFFECT OF TEMPERATURE ON INACTIVATION AND SURVIVAL: VIRUSES

Part II. PLANT VIRUSES

	Virus	Plant Source of Virus	Species	Test Conditions: Medium	Test Conditions: Temp., °C	Survival Time	Inactivation, °C	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
34	Potato X	*Lycopersicon esculentum*[8]	*Nicotiana tabacum* (Connecticut Havana) & *L. esculentum* (John Baer)	Leaves, air-dried	Room	1,251 da		13
35		*Nicotiana tabacum*	*N. tabacum* (Connecticut Havana) & *Lycopersicon esculentum* (John Baer)	Leaves, air-dried	Room	>286 da		13
36		*Nicotiana tabacum* (White Burley)	*N. tabacum* (White Burley)	Plant juice	14-17	>234 da	>70-<75	74
37		*Nicotiana rustica*	*N. rustica*	Plant juice	16-20	>360 da	72	42
38	Heat-resistant strains	*Nicotiana tabacum* (Samsun)	*N. tabacum* (Samsun)	Plant juice	Room		>72-<76	40
39		*Nicotiana tabacum* (White Burley)	*N. tabacum* (White Burley)	Plant juice	Room	4 mo	70	57
40	Heat-susceptible strains	*Nicotiana tabacum* (Samsun)	*N. tabacum* (Samsun)	Plant juice	Room		68	40
41		*Nicotiana tabacum* (White Burley)	*N. tabacum* (White Burley)	Plant juice	Room	4-5 mo	68	57
42	Mottle strain	*Nicotiana tabacum* (Connecticut Havana No. 38)	*N. tabacum* (Connecticut Havana No. 38)	Plant juice	Room	>28 da	>68-<70	38
43	Ring spot strain	*Nicotiana tabacum* (Connecticut Havana No. 38)	*N. tabacum* (Connecticut Havana No. 38)	Plant juice	Room	>28 da	>65-<68	38
44	Potato Y	*Datura metel*	*D. metel*	Plant juice	Room ?	2-3 da	55-60	12
45		*Nicotiana tabacum*	*N. tabacum*	Leaf tissue[9]	1-2	>78 da		44
46		*Nicotiana tabacum* ?	*N. tabacum* ?	Plant juice	15	>3-<4 da	57	23
47		*Nicotiana tabacum* & *Solanum tuberosum*	*N. tabacum* (Connecticut Havana No. 38)	Plant juice	Room ?	>6 da	60	39
48		*Nicotiana tabacum*[10]	*N. tabacum*[11]	Dried leaves	4	>16 mo		20
49				Plant juice	20-22	>6-<18 da	56-62	
50	Necrotic strain	*Nicotiana tabacum* (Samsun)	*N. tabacum* (Samsun)	Plant juice	21-23	>50 da	62	37
51		*Nicotiana tabacum* (White Burley)	*N. tabacum* (White Burley)	Plant juice	20	70 da	61	1
52	Pepper veinbanding mosaic strain	*Nicotiana tabacum* (Turkish)	*N. tabacum* (Turkish)	Plant juice, undiluted	23	>10-<15 da	61-65	66
53	Standard strain	*Nicotiana repanda*	*N. repanda*	Plant juice	10-15	3 da		47
54		*Nicotiana tabacum* (White Burley)	*N. tabacum* (White Burley)	Plant juice	20	12 da	60	1
55	Vein-necrosis strain	*Nicotiana tabacum* (White Burley)	*N. tabacum* (White Burley)	Plant juice	Room	<8 da	58	48
56	Potato aucuba mosaic	*Solanum tuberosum* (President)	*S. nodiflorum*	Plant juice	15 (dark)	>3-<4 da	>63-<65	16
57		*Nicotiana tabacum* ?	*N. sylvestris*	Plant juice	15	>4 da	68	24
58		*Nicotiana tabacum* (Samsun)	*Capsicum frutescens* (Early Calwonder)	Plant juice, dil. 1:9[4]	18-20 (dark)	30-90 da		41
59				Plant juice, dil. 1:4[4]			>65-<70	
60	Potato stem mottle, tobacco rattle strain	*Nicotiana tabacum* (Samsun)	*N. tabacum* (Samsun)	Plant juice, unpurified	20-22	>260 da		60
61				Dried leaves	20-22	>120 da		
62	Type M	*Nicotiana tabacum*	*Phaseolus vulgaris*	Plant sap, dil. 1:99[4]	20	>6 wk		14
63				Plant sap, dil. 1:4[4]			>80-<85	
64				Frozen plant juice	-10	>15 mo		
65	Potato yellow dwarf	*Nicotiana rustica*	*N. rustica*	Plant juice	23-27	>12 hr	52	10

/4/ With water. /8/ Also infected with tobacco mosaic virus. /9/ Finely cut and dried over $CaCl_2$. /10/ Recently infected. /11/ Infected with potato X virus.

continued

115. EFFECT OF TEMPERATURE ON INACTIVATION AND SURVIVAL: VIRUSES

Part II. PLANT VIRUSES

	Virus	Plant Source of Virus	Species	Test Conditions: Medium	Test Conditions: Temp., °C	Survival Time	Inactivation, °C	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
66	Potato yellow dwarf	*Nicotiana rustica*	*N. rustica*	Juice from frozen leaves	13-15	>1-<7 mo		11
67				Juice in KH_2PO_4 buffer	0	>7 da		11
68				Buffer[13]	0	>4 wk		11
69	Sugar beet curly top	*Beta vulgaris*	*B. vulgaris*	Phloem exudate, dil.[13]			80	7
70				Plant leaf juice	Room	>7-<14 da		
71		*Beta vulgaris*[14]	*B. vulgaris*	Dried natural exudate	Room	>10 mo		7
72		*Beta vulgaris*	*B. vulgaris*	Exudate[15]	Room	>5 mo		7
73				Dried leaves[16]	Room[17]	8 yr		8
74	Tobacco etch virus	*Nicotiana glutinosa*	*Physalis peruviana*	Dried plant juice[18]	Room	>10 da		31
75		*Nicotiana tabacum*	*Physalis peruviana*	Plant juice, dil. 1:10[19]	Above freezing point	>10 da		31
76			*N. tabacum*	Plant leaf tissue[1]	1-2	>301 da		44
77			*N. tabacum* (starch-iodine method)	Plant juice	Room	13 da	58	5
78				Dried leaves	Room	[illegible] da		
79	Tobacco mosaic	*Nicotiana tabacum* (Turkish)	*N. glutinosa* & *Phaseolus vulgaris* (Early Golden Cluster)	Plant juice, dil. 1:20[4]	68	[illegible]0 da		54
80				Plant juice, dil. 1:20[4]			93	
81			*N. glutinosa*	Plant juice	10-15	49 da		47
82		*Nicotiana tabacum* (White Burley)	*N. tabacum* (Turkish)	Whole leaves, dried	Room	52 yr		33
83	Tobacco necrosis	*Nicotiana tabacum*	*Vigna sinensis ?*	Plant juice, dil. 1:30	29	>9-<40 da		71
84				Plant juice, dil. 1:5	2	>40 da		
85		*Nicotiana tabacum ?*	*Vigna sinensis ?*	Plant juice[20]	Room	>6 mo		69
86	Bean strain	*Phaseolus vulgaris*	*P. vulgaris* (Pinto U.I. 111)	Plant juice	18	22 da	85-90	6
87	Tobacco ring spot	*Phaseolus vulgaris*	*P. vulgaris*	Plant juice	Room	7-9 da	66	53
88		*Nicotiana rustica*	*N. tabacum*	Plant juice, kept dark	26-32	>6 da	>65-<70	35
89		*Nicotiana sylvestris*	*N. tabacum*	Plant juice, kept dark	26-32	>1-<2 da	>60-<65	35
90		*Nicotiana tabacum*	*N. tabacum*	Plant juice, kept dark	26-32	6 da	>65-<70	35
91			*N. tabacum*[16]	Plant juice	Room	>12-<24 hr	>60	30
92			*N. tabacum*	Plant juice	15	>1-<3 da		55
93				Plant juice	5	>17-<19 da		
94		*Nicotiana tabacum* & *Petunia hybrida*	*N. tabacum*[16]	Plant juice	-18	>22 mo		30
95		*Nicotiana tabacum*	*N. tabacum*	Leaf tissue[9]	1-2	>393 da		44
96	Common strain	*Lactuca sativa*	*Nicotiana tabacum?*	Plant juice	23	36-48 hr		25
97	Eucharis strain	?	?	Plant juice	Room	6-8 da	65	36
98	Lettuce calico strain	*Nicotiana tabacum*	*N. tabacum?*	Plant juice	23	72-96 hr		25
	Tobacco streak							
99	Standard strain	*Phaseolus vulgaris* (Pinto U.I. No. 78)	*P. vulgaris* (Pinto U.I. No. 78)	Plant juice	18	<24 hr	54-56	73
100				Plant leaves[21]	18	>90 da		
101		*Nicotiana tabacum* (Havana)	*N. tabacum* (Havana)	Plant juice	22	>24-<36 hr	53	34

/1/ Desiccated above freezing temperature. /4/ With water. /9/ Finely cut and dried over $CaCl_2$. /12/ Partially purified virus in buffer. /13/ With sugar solution. /14/ Petioles. /15/ Dried alcoholic precipitate. /16/ Young plant. /17/ Kept over $CaCl_2$ in airtight container. /18/ Resuspended residue. /19/ In presence of acid buffer. /20/ Dried precipitate or in absolute alcohol. /21/ Air-dried at 20-25°C.

continued

115. EFFECT OF TEMPERATURE ON INACTIVATION AND SURVIVAL: VIRUSES

Part II. PLANT VIRUSES

	Virus	Plant Source of Virus	Species	Test Conditions: Medium	Test Conditions: Temp., °C	Survival Time	Inactivation, °C	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
	Tobacco streak							
102	Bean red node strain	*Phaseolus vulgaris* (Pinto U.I. No. 78)	*P. vulgaris* (Pinto U.I. No. 78)	Plant juice	18	>24-<48 hr		73
103				Plant leaves[21]	18	>30-<90 da		
104	Brazilian strain	*Nicotiana tabacum*	*N. tabacum*	Plant juice	Room	>12-<24 hr	50-55	19
105		*Nicotiana tabacum* (recovered tissue)	*N. tabacum* (Turkish)	Plant juice[22]	Room ?	>9-<27 hr	>60-<65	18
106	Canadian strain	*Nicotiana tabacum ?*	*N. tabacum ?*	Plant juice	Room	<24 hr	54	9
107	Pea strain	*Phaseolus vulgaris*	*P. vulgaris* (Pinto U.I. 111)	Plant juice	22	>26-<27 hr	64	52
108				Plant leaves[23]	22	>98 da		
109	Tomato aspermy	*Nicotiana tabacum*		Plant juice	23-25	>12 hr	70	49
110	Tomato bunchy top	*Lycopersicon esculentum*	*Nicotiana glutinosa*	Plant juice	Room	>24 hr	70	43
111	Tomato bushy stunt	*Lycopersicon esculentum*	*Vigna sinensis*	Plant juice	Room	33 da	80	68
112	Tomato mosaic	*Lycopersicon esculentum*	*L. esculentum*	Plant juice	Room	>138 da	85-90	75
113				Dry tissue	Room	Indefinite	85-90	
114	Tomato ring spot	*Lycopersicon esculentum*	*Datura stramonium*	Plant juice	Room	>21-<27 hr		58
115			*L. esculentum*	Plant juice	Room		>56-<58	58
116				Dry tissue	Room	<300 hr	58	
117	Beet ring spot strain	*Nicotiana tabacum* (White Burley)	*Phaseolus vulgaris ?*	Plant juice	20	>2-<3 wk	>63-<66	29
118	Brazilian strain	*Lycopersicon esculentum*	*Nicandra physalodes*	Plant juice	25	>13-<20 da		65
119	Tomato black ring strain	*Nicotiana tabacum ?*	*N. tabacum ?*	Plant juice	Room	>7 da	>58-<62	70
120	Tomato ring spot strain & peach yellow bud strain	*Petunia hybrida*	*P. hybrida*	Plant juice, dil. 1:4[4]	-10	>5 da	>60-<65	15
121	Tomato spotted wilt	*Lycopersicon esculentum*[10]	*L. esculentum*	Plant juice, dil.[4]	16	>4.5-<6 hr	>39-<42	3
122		*Lycopersicon esculentum*[10,16]	*L. esculentum*[16]	Plant juice, untreated	21	>2 hr	>44-<46	50
123		*Lycopersicon esculentum*	*Nicotiana glutinosa*	Plant juice	Room	5 hr	42	59
124		*Lycopersicon esculentum* (top leaves)	*Nicotiana tabacum* (Blue Pryor)	Plant juice, dil.[4]	20-22	<7 hr		4
125				Plant juice[24]	20-22	>36 hr		
126		*Nicotiana tabacum* (White Burley)	*N. glutinosa* or *Petunia hybrida*	Plant juice, dil.[4]	Room	3.5 hr		67
127			*N. tabacum* (White Burley)	Plant juice, dil.[4]	Room	2 hr		
128	Corcova strain	*Lycopersicon esculentum*	*L. esculentum* & *Nicotiana glutinosa*	Plant juice	21	<2.5 hr	>46-<48	21
129	Tomato tip blight strain	*Lycopersicon esculentum*	*L. esculentum*	Plant juice, undiluted	18	<1 hr	41.5	46
130	Tropaeolum mosaic	*Tropaeolum majus*	*T. majus*	Plant juice	25	<24 hr	58	64
131	Brazilian strain	*Tropaeolum majus*	*T. majus*	Plant juice	3	>3 da		64
132	California strain	*Tropaeolum majus*	*T. majus*	Plant juice	Room	4 da	55	32
133	Ring mosaic strain	*Chenopodium quinoa*	*C. quinoa*	Plant juice	Room	>11-<18 da	>66-<68	61
134		*Nicotiana glutinosa*	*N. glutinosa*	Plant juice	Room	<3 da		61
135				Dried leaves	Room	>8-<9 da		
136		*Nicotiana alata*	*N. alata*	Plant juice	Room	5 da	>65-<68	62
137				Dried leaves	Room	>2-<3 wk		
138	Ring spot mosaic strain	*Nicotiana tabacum* (Samsun)	*Chenopodium quinoa*	Plant juice, purified	Room (dark)	>24-<30 da	62-65	63

/4/ With water. /10/ Recently infected. /16/ Young plant. /21/ Air-dried at 20-25°C. /22/ In 0.02 *M* phosphate buffer plus sodium sulfite. /23/ Air-dried and powdered. /24/ In 0.2% solution of sodium sulfite.

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continued

115. EFFECT OF TEMPERATURE ON INACTIVATION AND SURVIVAL: VIRUSES

Part II. PLANT VIRUSES

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116. EFFECT OF TEMPERATURE ON GROWTH AND SURVIVAL: RICKETTSIA AND BACTERIA

Values are for data obtained under diverse conditions by many investigators. Data may differ for various species within the same genus, and even for various cultures of the same species.

Part 1. OPTIMUM TEMPERATURE FOR GROWTH

Bacteria may be grouped on the basis of their optimum growth temperatures; psychrophiles (optima below 20°C), mesophiles (optima from 21°-50°C), and thermophiles (optima above 50°C). These groupings are arbitrary and not mutually exclusive. Some bacteria, with optima below 50°C but which grow well at temperatures above 50°C, are not true thermophiles, as defined above, and are called thermoduric. Values in parentheses are for minimum and maximum temperatures at which growth can occur.

	Species	Temp. °C	Reference
	(A)	(B)	(C)
	Rickettsia		
1	*Bartonella bacilliformis*	28 (max. 37)	2,5,9,13
2	*Coxiella burneti*	35	11
3	*Miyagawanella lymphogranulomatis*	35-37	2
4	*Rickettsia prowazekii*	34-36 (30-37)	11
	Bacteria		
5	*Actinomyces bovis*	37 (20-40)	4
6	*Aerobacter aerogenes*	37 (2.5-45)	7
7	*Agrobacterium tumefaciens*	25-30 (0-37)	6,14
8	*Azotobacter chroococcum*	25-28	2
9	*Bacillus subtilis*	28-40 (max. 50-55)	2
10	*Brucella melitensis*	37 (6-45)	3
11	*Clostridium botulinum*	25 (20-35)	10
12	*Corynebacterium diphtheriae*	34-36 (15-40)	3
13	*Diplococcus pneumoniae*	37 (25-42)	3
14	*Erwinia carotovora*	25-30 (4-39)	6
15	*Escherichia coli*	30-37 (10-45)	2
16	*Lactobacillus acidophilus*	37 (22-48)	2
17	*Mycobacterium tuberculosis*	37 (30-42)	2,3
18	*Neisseria gonorrhoeae*	37 (30-39)	3,4
19	*Photobacterium fischeri*	25-28 (min. 5-10)	2
20	*Proteus vulgaris*	30-37 (good at 20)	3
21	*Pseudomonas aeruginosa*	37 (5-42)	13
22	*Rhizobium leguminosarum*	25	2,8,10
23	*Salmonella typhosa*	37 (4-40)	12
24	*Shigella dysenteriae*	37 (10-40)	5,13
25	*Staphylococcus aureus*	35-37 (10-42)	4
26	*Streptococcus pyogenes*	37 (10-42)	3
27	*Streptomyces griseus*	30-37	1,2
28	*Vibrio comma*	37 (16-42)	3
29	*Xanthomonas campestris*	30-32 (5-39)	6,14

Contributor: Dupré, Margaret V.

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continued

116. EFFECT OF TEMPERATURE ON GROWTH AND SURVIVAL: RICKETTSIA AND BACTERIA

Part II. THERMAL DEATH TIME

Bacteria which do not form endospores are generally killed within 20 minutes when directly exposed in fluid to temperatures of 70°C or over (moist heat), but thermophiles are somewhat more resistant. Bacterial endospores may resist moist heat at 100°C for two minutes to many hours. However, no known living organism can survive compressed steam at 121°C (routine autoclaving) for 20 minutes. The thermal death times listed below are generally based on exposure to moist heat, unless otherwise specified. Inconsistencies in the values may be attributed to different experimental methods and to the fact that all of the variables, especially pH (a crucial factor), were not always reported. **Substrate** (column B): PS = phosphate solution; PW = peptone water.

	Species	Substrate	Temp. °C	Time min	Reference
	(A)	(B)	(C)	(D)	(E)
	Rickettsia				
1	*Coxiella bur-*		50	30	23
2	*neti*	Egg yolk sac	63-65	30	22
3		Milk	62.2	30	7
4		Milk[1]	62.7	30-40	14
5		Milk[2]	67.7-68.7	0.25	17
6		Milk[3]	71.6	0.25	18
7		Milk	72.2	0.25	7
8	*Miyagawanella lymphogranulomalis*		60	10	15
9	*Rickellsia prowazekii*		56	30	23
	Bacteria				
10	*Aclinomyces bovis*		62-64	3-10	28
11	*Acrobacler*	Milk	57.2	<60	10
12	*aerogenes*		60	30	2
13	*Bacillus subli-*	PS, pH 4.4	100	2	11
14	*lis*	PS, pH 5.6	100	7	11
15		PS, pH 6.8-7.6	100	11	11
16		PS, pH 8.4	100	9	11
17		1% PW[4]	100	11	11
18		1% PW[5]	100	16	11
19	*Brucella meli-*	Moist	60	10	3
20	*tensis*		65	5	3
21		Aqueous emulsion	57.5	10	13
22		Milk	61.1-62.7	30	5
23		0.85% NaCl	62.5	10	1
24	*Clostridium*	2% aminoids	100	65	9
25	*botulinum*	Corn (canned)	100	105	12
26			115	15	12
27		Pears	100	30	12
28		(canned)	115	5	12
29		PS, pH 7	100	330	9
30			110	32	9
31			115	10	9
32			120	4	9
33	*Corynebacte-*	Broth	58	10	5
34	*rium diph-*	Ice cream	65.6	0.5	20
35	*theriae*	Milk	55-60	2	24
36		Water	58	10	25
37			100	1	25
38	*Diplococcus*		52	10	25
39	*pneumoniae*		55	20	3
40		Blood broth	56	5-7	19
41		Broth[6]	60	30	13
42		Melted dextrose agar	60	15	13
43	*Escherichia*	Milk	57.2	>60	10
44	*coli*		60	30	5,8
45			62.5	30	27
46	*Lactobacillus thermophilus*		71	30	2
47	*Lactobacillus thermophilus*		82	2.5	2
48	*Mycobacteri-*		58	30	5
49	*um tubercu-*		59	20	5
50	*losis*		65	2	5
51		Ice cream	62.6	6	20
52		Milk	55	60	10
53			60	10	10
54			65	2	10
55			71	$\frac{1}{3}$	10
56			82	$<\frac{1}{3}$	10
57			100	$<\frac{1}{6}$	10
58		Sputum	100	15	29
59		Sputum (dried)	100	60	5
60	*Neisseria*	Infected pus[7]	42	300-900	6
61	*gonorrhoeae*		50	5	13
62		Moist	55	5	25
63			55	5	7.8
64	*Proteus vulgaris*		55	60	3
65	*Pseudomonas aeruginosa*		55	60	8,25
66	*Salmonella*	Broth	55	23.8	27
67	*typhosa*		56	4-9	19
68			60	4.3	11
69		Ice cream	57.2	10	20
70			62.8	3	20
71		Milk	55	30	24
72			60	20	13
73			61.1-62.7	4-8	27
74		Milk[6]	60	8	13
75			63	4	13
76	*Shigella dys-*		55	60	7
77	*enteriae*	Milk	60	6	27
78		Milk[6]	60	10	21
79		Water	60	1	27
80	*Staphylococcus*		60	30-60	8
81	*aureus*		62	30	7
82		Broth	65.6	2	26
83		Broth[6]	58	10	13
84		Broth	65	18.8	27
85		Custard filling	88	10	11
86		Skimmed milk & 14% sugar	60	30	16
87		Dry heat	190.6-218.3	30	11
88	*Streptococcus*		54	30	7
89	*pyogenes*	Milk	60	15	4
90		Cream	57.2	5	20
91			61.1	1	20
92		Diluted salt-gelatin	60	10	13
93		Melted dextrose agar	60	15	13
94		Milk	62	30	25
95	*Vibrio comma*		55	10	5,25

/1/ Sealed tubes in water. /2/ Naturally infected. /3/ Artificially infected. /4/ Incubated at 21°-23°C. /5/ Incubated at 37°C. /6/ In sealed tubes. /7/ In sealed pipette.

continued

116. EFFECT OF TEMPERATURE ON GROWTH AND SURVIVAL: RICKETTSIA AND BACTERIA

Part II. THERMAL DEATH TIME

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117. EFFECT OF TEMPERATURE ON GROWTH AND SURVIVAL: FUNGI

Values in parentheses are for minimum (min.) and maximum (max.) temperatures at which growth can occur.

	Species	Temperature for Growth[1] °C	Thermal Death Temp. °C	Thermal Death Time min	Reference
	(A)	(B)	(C)	(D)	(E)
	Animal Pathogens				
1	*Aspergillus niger*	37 (max. <60)	....	...	8
2	*Candida albicans*	30-37 (<20->40)	60	10	2-4,7
3	*Cladosporium mansoni*	30-32	....	...	1,5
4	*Rhizopus equinus*	37-39 (min. >5)	100	20	1
5	*Torulopsis famata*	25-37	....	...	1
	Plant Pathogens				
6	*Alternaria brassicae*	33-35 (1-46)[2]; 25-27 (2-36)	55	10	6
7	*Aspergillus niger*[3]	30-39 (7-46)	99[4]; 62[5]	10	6
8	*Cladosporium fulvum*[3]	18-26 (0-33)[2]; 16-26 (0-34)	70[4]	10	6
9	*Fusarium oxysporum*[6]	15-32 (4-40)	57	10	6
10	*Helminthosporium turcicum*	28-30 (7-35)	....	...	6

/1/ In culture, unless otherwise specified. /2/ Spore germination. /3/ Fungus exhibits variability among different strains or in different hosts. /4/ Dry. /5/ Wet. /6/ Fungus exhibits extreme variability among different strains or in different hosts.

continued

117. EFFECT OF TEMPERATURE ON GROWTH AND SURVIVAL: FUNGI

	Species	Temperature for Growth[1] °C	Thermal Death		Reference
			Temp. °C	Time min	
	(A)	(B)	(C)	(D)	(E)
	Plant Pathogens				
11	*Penicillium expansum*	25-27 (0-30)	....	...	6
12	*Puccinia graminis*	5-25 (2-35)	....	...	6
13	*Rhizopus nigricans*[3]	19-41 (2-41)[2]; 20-36 (2-40)	55[7]	10	6
14	*Ustilago hordei*[3]	10-30 (0-35)[2]; 16-26 (<1-<35)	43-48	10	6
15	*Venturia inaequalis*	13-25 (0-35)[2]; 20 (<4-<32)	....	...	6

/1/ In culture, unless otherwise specified. /2/ Spore germination. /3/ Fungus exhibits variability among different strains or in different hosts. /7/ Spores.

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118. TEMPERATURE TOLERANCES: ALGAE

Most values were based on observations of algae growing in their natural habitat. Since it is difficult to determine true temperature under such conditions, and since light absorption may raise the temperature of an algal mass above that of its surroundings, the data should be interpreted with caution. Values in parentheses are temperatures for maximum growth rate.

	Species	Temperature, °C		Reference
		Minimum	Maximum	
	(A)	(B)	(C)	(D)
	Cyanophyta			
1	*Anabaena variabilis*	....	(35)	4
2	*Chroococcus yellowstonensis*	....	41	2
3	*Nostoc muscorum*	....	(33)	4
4	*Oscillatoria filiformis*	59	85 (73)	2
5	*Phormidium bijahensis*	38	85 (60-62)	2
6	*Synechococcus eximius*	70	84 (79)	2
	Chlorophyta			
7	*Chlamydomonas nivalis*	-36	4 (0)	3
8	*Chlorella pyrenoidosa* (Emerson)	....	29 (25-26)	8
9	*Chlorella pyrenoidosa* (7-11-05)	....	42 (38-39)	8
10	*Cladophora hamosa*	<-7	>35	1
11	*Protococcus botryoides*	....	80	2
12	*Ulothrix* sp.	....	17	7
	Phaeophyta			
13	*Fucus vesiculosus*	-18 to -20[1]	30	5,6
14	*Laminaria saccharina*	-4 to -6[2]; -11 to -17[3]	....	6
	Rhodophyta			
15	*Polysiphonia pulvinata*	<-7	>30	1
16	*Porphyra leucosticta*	<-7	>30	1

/1/ Based on observations in polar seas; uncertain that algae were actually growing. /2/ One-year-old algae. /3/ More than one year old.

Contributors: (a) Allen, Mary Belle, (b) Pisek, A., (c) Sorokin, Constantine

References: [1] Biebl, R. 1939. Jahrb. Wiss. Botan. 88:389. [2] Copeland, J. J. 1936. Ann. N. Y. Acad. Sci. 36:1. [3] Huber-Pestalozzi, G. 1926. In C. Schröter, ed. Das Pflanzenleben der Alpen. Raustein, Zurich. p. 942. [4] Kratz, W. A., and J. Myers. 1955. Am. J. Botany 42:282. [5] Kylin, H. 1910. Arkiv Botan. 10(1):1. [6] Kylin, H. 1917. Ber. Deut. Botan. Ges. 35:370. [7] Oltmans, F. 1923. Morphologie und Biologie der Algen. G. Fischer, Jena. v. 3. [8] Sorokin, C. 1959. Nature 184:613.

119. SOIL pH: SPERMATOPHYTES

With good management, and if other factors are favorable, many of the plants listed will grow and develop satisfactorily outside the pH range indicated. Field crops and vegetables generally are not as sensitive to soil pH as are flowers and shrubs.

	Species (Common Name)	pH	Reference
	(A)	(B)	(C)
	Gymnospermae		
1	*Abies* spp. (fir)	4.5-6.5	4
2	*Ginkgo biloba* (ginkgo)	5.5-7.0	4
3	*Juniperus virginiana* (eastern red cedar)	5.0-8.0	4
4	*Larix* spp. (larch)	4.5-7.5	4
5	*Picea* spp. (spruce)	4.5-6.5	4
6	*Pinus* spp. (pine)	4.5-6.5	4
7	*Taxus* spp. (yew)	5.0-7.5	4
8	*Thuja occidentalis* (northern white cedar)	6.0-7.5	3
9	*Tsuga canadensis* (eastern hemlock)	4.5-6.0	4
	Angiospermae (Monocotyledoneae)		
10	*Allium cepa* (garden onion)	6.0-7.5	4
11	*Asparagus officinalis* (garden asparagus)	6.0-8.0	3
12	*Avena sativa* (common oat)	5.0-7.5	2,3
13	*Gladiolus* spp. (gladiolus)	6.0-8.0	1
14	*Hordeum vulgare* (barley)	6.0-7.5	4
15	*Iris* spp. (iris)	6.0-8.0	1
16	*Lilium longiflorum* (Easter lily)	6.0-7.0	3
17	*Oryza sativa* (rice)	5.0-6.5	2,3
18	*Phleum pratense* (timothy)	6.0-8.0	3
19	*Poa pratensis* (Kentucky bluegrass)	5.5-7.5	2,3
20	*Tradescantia virginiana* (Virginia spiderwort)	5.0-7.5	3
21	*Triticum aestivum* (wheat)	5.5-7.5	2
22	*Zea mays* (corn)	5.5-7.5	2,3
	Angiospermae (Dicotyledoneae)		
23	*Acer* spp. (maple)	5.5-7.5	4
24	*Alnus* spp. (alder)	6.0-7.5	4
25	*Antirrhinum majus* (snapdragon)	6.0-7.5	3
26	*Beta vulgaris* (common beet)	6.0-7.5	3
27	*Betula lenta* (sweet birch)	4.5-6.0	4
28	*Capsicum frutescens* (bush red pepper)	5.5-7.0	1
29	*Carya ovata* (shagbark hickory)	6.0-6.5	4
30	*Catalpa* spp. (catalpa)	6.0-7.5	4
31	*Chrysanthemum morifolium* (florist's chrysanthemum)	6.0-7.5	3
32	*Citrus limon* (lemon)	6.0-7.5	3
33	*C. sinensis* (sweet orange)	6.0-7.5	3
34	*Cornus florida* (flowering dogwood)	5.0-6.5	4
35	*Cucumis sativus* (cucumber)	5.5-7.0	3
36	*Cucurbita pepo* (pumpkin)	5.5-7.0	1
37	*Daucus carota* (carrot)	5.5-7.0	3
38	*Fagopyrum esculentum* (buckwheat)	5.5-7.0	2,3
39	*Fagus sylvatica* (European beech)	6.0-7.5	4
40	*Fragaria* spp. (strawberry)	5.0-6.5	1,3
41	*Glycine soja* (soybean)	6.0-7.5	4
42	*Gossypium hirsutum* (upland cotton)	5.0-6.5	4
43	*Helianthus annuus* (common sunflower)	6.0-7.5	2,3
44	*Ilex aquifolium* (English holly)	5.0-6.5	4
45	*Ipomoea batatas* (sweet potato)	5.0-6.5	4
46	*Juglans* spp. (walnut)	6.0-7.5	4
47	*Lactuca sativa* (lettuce)	6.0-7.5	4
48	*Lycopersicon esculentum* (tomato)	5.5-7.5	3
49	*Magnolia grandiflora* (southern magnolia)	5.0-7.0	1
50	*Malus pumila* (common apple)	5.0-6.5	3
51	*Medicago sativa* (alfalfa)	6.2-7.8	2,3
52	*Nicotiana tabacum* (common tobacco)	5.5-7.5	2,3
53	*Oenothera biennis* (common evening primrose)	6.0-8.0	3
54	*Phaseolus vulgaris* (kidney bean)	6.0-7.5	2,3
55	*Pisum sativum* (garden pea)	6.0-8.0	1
56	*Populus tremuloides* (quaking aspen)	4.5-5.5	4
57	*Prunus persica* (peach)	6.0-7.5	3
58	*Pyrus communis* (pear)	6.0-7.5	3
59	*Quercus alba* (white oak)	6.0-8.0	1
60	*Raphanus sativus* (garden radish)	5.5-7.0	4
61	*Rhododendron obtusum amoenum* (amoena azalea)	4.5-6.0	3
62	*Rosa* sp. (hybrid tea rose)	5.5-7.0	3
63	*Salix* spp. (willow)	5.5-7.5	4
64	*Solanum tuberosum* (potato)	5.0-6.5	2,3
65	*Trifolium pratense* (red clover)	6.0-7.5	2,3
66	*Ulmus americana* (American elm)	6.0-8.0	1
67	*Vicia faba equina* (horsebean)	6.0-7.0	3
68	*Vitis* spp. (grape)	6.0-8.0	1

Contributors: (a) Walker, Richard B., (b) Wherry, Edgar T., (c) Bennett, W. F.

References: [1] Bennett, W. F. 1953. Texas Agr. Expt. Sta. Ext. Serv. Leaflet 164. [2] Ignatieff, V. 1949. Food Agr. Organ. U. N. Agr. Studies 9:108. [3] Spurway, C. H. 1941. Mich. State Univ. Agr. Expt. Sta. Spec. Bull. 306. [4] Wherry, E. T. Unpublished. Univ. Pennsylvania, Philadelphia, 1954.

120. SHADE TOLERANCE: VASCULAR PLANTS

Tolerance (column B): T = highly tolerant; t = moderately tolerant; I = intermediate; ŧ = moderately intolerant; Ŧ = highly intolerant.

	Species (Common Name)	Tolerance	Reference
	(A)	(B)	(C)
	Pteridophyta		
1	*Adiantum pedatum* (American maidenhair)	T	4
2	*Equisetum hyemale* (scouring rush)	T	2
3	*Lycopodium lucidulum* (shining club moss)	T	2
4	*Polypodium virginianum* (rock polypody)	t	4
	Gymnospermae		
5	*Abies concolor* (white fir)	t	1,4
6	*Ginkgo biloba* (ginkgo)	ŧ	2
7	*Juniperus virginiana* (eastern red cedar)	ŧ	1,8
8	*Larix* spp. (larch)	Ŧ	1,8
9	*Picea glauca* (white spruce)	t	1,8
10	*Pinus strobus* (eastern white pine)	I	1,8
11	*Sequoia gigantea* (giant sequoia)	I	1
12	*Taxodium distichum* (bald cypress)	I	1,8
13	*Taxus canadensis* (Canada yew)	T	4
14	*Thuja occidentalis* (northern white cedar)	t	1,8
15	*Tsuga canadensis* (eastern hemlock)	T	1,8
	Monocotyledoneae		
16	*Iris cristata* (crested iris)	I	4
17	*Lilium* spp. (lily)	ŧ	5
18	*Poa trivialis* (roughstalk bluegrass)	t	3
19	*Tradescantia virginiana* (Virginia spiderwort)	T	7
	Dicotyledoneae		
20	*Acer saccharinum* (silver maple)	t	1
21	*Beta vulgaris* (common beet)	I	6
22	*Betula lenta* (sweet birch)	I	1
23	*Carya illinoensis* (pecan)	ŧ	1,8
24	*Catalpa bignonioides* (southern catalpa)	ŧ	2
25	*Chrysanthemum* spp. (chrysanthemum)	I	7
26	*Cornus florida* (flowering dogwood)	T	1
27	*Digitalis purpurea* (common foxglove)	t	2
28	*Fagus grandifolia* (American beech)	T	1,8
29	*Fraxinus americana* (white ash)	I	1,2
30	*Ilex opaca* (American holly)	T	1
31	*Juglans nigra* (black walnut)	ŧ	1,2
32	*Lactuca sativa* (lettuce)	ŧ	6
33	*Lycopersicon esculentum* (tomato)	I	6
34	*Malus coronaria* (sweet crab apple)	I	2
35	*Phlox divaricata* (Sweet William phlox)	T	7
36	*Populus deltoides* (eastern poplar)	Ŧ	1,8
37	*Prunus serotina* (black cherry)	ŧ	1
38	*Quercus alba* (white oak)	I	1,8
39	*Rhododendron* spp. (rhododendron)	T	4
40	*Ribes americanum* (American black currant)	T	2
41	*Salix* spp. (willow)	Ŧ	1,2
42	*Solanum melongena* (eggplant)	I	6
43	*Ulmus americana* (American elm)	I	1,2

Contributors: (a) Clapp, Grace L., (b) Kramer, Paul J., (c) Roe, Eugene I.

References: [1] Baker, F. S. 1949. J. Forestry 47:179. [2] Clapp, G. L. Unpublished. Windsor, Connecticut, 1952. [3] Curtis, R. W., and J. F. Cornman. 1941. N. Y. State Agr. Expt. Sta. (Geneva) Bull. 465. [4] Morse, H. K. 1962. Gardening in the shade. Rev. ed. Scribner's Sons, New York. [5] Taylor, N. 1961. Encyclopedia of gardening. Houghton Mifflin, Boston. [6] Went, F. W. 1946. Proc. Am. Soc. Hort. Sci. 48:374. [7] Williams, F. R. 1949. J. N. Y. Botan. Garden 50:201. [8] Zon, R., and H. S. Graves. 1911. U.S. Dept. Agr. Forest Serv. Bull. 92.

121. EFFECT OF LIGHT ON DEVELOPMENT: ANGIOSPERMS

Part I. VARIOUS WAVELENGTHS

Data present the effectiveness of brief interruption of the dark period to control flowering and certain vegetative expressions. Plants were grown under radiation from carbon arc and incandescent filament lamps for a daily period of approximately 12 hours. Midpoint in the dark period they were exposed to radiation of known energy and wavelength.

	Effect and Species (Common Name)	Relative Energy Normalized to Maximum Response at Wavelength (Ångstrom Units) of											Conversion Factor[1]	Reference
		4400	4800	5000	5200	5400	5600	5800	6200	6600	6800	7000		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)
	Inhibition of flowering													
1	*Glycine soja* (soybean)	18	27	17	6	3.7	2	1.3	1	1.3	1.6	3.5	30	8,9
2	*Xanthium pensylvanicum* (cocklebur)	125	173	92	40	8	5.4	2.6	1[2]	1.5	3.1	7	40	3,8

/1/ Relative energy (columns B-L) may be converted to kiloergs per sq cm by multiplying by the appropriate factor (column M). /2/ 7200-7600 Å reverses the response caused by red (6200-6600 Å).

continued

121. EFFECT OF LIGHT ON DEVELOPMENT: ANGIOSPERMS

Part I. VARIOUS WAVELENGTHS

	Effect and Species (Common Name)	Relative Energy Normalized to Maximum Response at Wavelength (Ångstrom Units) of 4400	4800	5000	5200	5400	5600	5800	6200	6600	6800	7000	Conversion Factor[1]	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)
	Promotion of flowering													
3	*Hordeum vulgare* (barley)	218	185	85	35	4	1.8	1.3	1[a]	1.5	4	7	35	1,5,6
4	*Hyoscyamus niger* (black henbane)	...	...	...	...	4	1.8	1.3	1[a]	1.5	4	7	300	5-7
	Promotion of germination													
5	*Lactuca sativa* (lettuce)	...	...	...	...	...	18	10	3[a]	1	1.2	50	2	4
	Promotion of leaf elongation													
6	*Pisum sativum* (garden pea)	100	190	200	95	24	10	6.5	1	1	1	1.3	0.16	9
	Inhibition of stem elongation													
7	*Hordeum vulgare* (barley)	250	...	200	40	20	5	2	1.3[a]	1	2	6	100	2,5,6
	Production of pigmentation													
8	*Lycopersicon esculentum* (tomato)	30	30	30	30	20	10	3	1[a]	1	1.2	7	200	10

/1/ Relative energy (columns B-L) may be converted to kiloergs per sq cm by multiplying by the appropriate factor (column M). /a/ 7200-7600 Å reverses the response caused by red (6200-6600 Å).

Contributor: Downs, R. J.

References: [1] Borthwick, H. A., S. B. Hendricks, and M. W. Parker. 1948. Botan. Gaz. 110:103. [2] Borthwick, H. A., S. B. Hendricks, and M. W. Parker. 1951. Ibid. 113:95. [3] Borthwick, H. A., S. B. Hendricks, and M. W. Parker. 1952. Proc. Natl. Acad. Sci. U.S. 38(1):929. [4] Borthwick, H. A., et al. 1952. Ibid. 38(8):662. [5] Downs, R. J. 1955. Plant Physiol. 30:468. [6] Downs, R. J. 1956. Ibid. 31:279. [7] Parker, M. W., S. B. Hendricks, and H. A. Borthwick. 1950. Botan. Gaz. 111:242. [8] Parker, M. W., et al. 1945. Science 102:152. [9] Parker, M. W., et al. 1946. Botan. Gaz. 108:1. [10] Piringer, A. A., and P. H. Heinze. 1954. Plant Physiol. 29:467.

Part II. VARIOUS EXPOSURES

	Species (Common Name)	Beginning of Test	Photoperiodic Classification	Light Exposure hr	Development: Budding da	Flowering da	Height cm
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
1	*Agrostis nebulosa* (cloud bent grass)	May 14	Long day	13.0	49	58	25.4
2				13.5	48	58	33.0
3				14.0	37	45	27.9
4				14.5	35	41	40.6
5				24.0	34	48	27.9
6	*Antirrhinum majus* (snapdragon)	May 31	Indeterminate	10.0	28	45	40.6
7				12.0	24	35	30.5
8				13.0	20	33	35.6
9				14.0	20	35	40.6
10				24.0	20	33	33.0
11	*Chrysanthemum* sp. (chrysanthemum)[1]	....	Indeterminate	10.0	21	54	40.6
12				12.0	24	54	33.0
13				12.5	24	54	40.6
14				13.0	25	59	35.6
15				13.5	24	56	50.8
16				14.0	38	73	48.3
17				14.5	38	78	50.8
18				24.0	46	71	45.7
19	*Convolvulus sepium* (hedge glorybind)	May 19	Long day	13.5	44	59	101.6
20				24.0	35	49	114.3
21	*Glycine soja* (soybean)	May 25	Short day	10.0	20	23	22.9
22				12.0	21	27	35.6

/1/ Yellow Normandie variety.

continued

121. EFFECT OF LIGHT ON DEVELOPMENT: ANGIOSPERMS

Part II. VARIOUS EXPOSURES

	Species (Common Name)	Beginning of Test	Photoperiodic Classification	Light Exposure hr	Development: Budding da	Development: Flowering da	Development: Height cm
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
23	*Glycine soja* (soybean)	May 25	Short day	12.5	24	27	45.7
24				13.0	25	31	40.6
25				13.5	34	37	48.3
26				14.0	42	48	68.6
27				14.5	50	60	76.2
28				24.0	81	90	96.5
29	*Hibiscus syriacus* (shrub althea)	March 27	Long day	12.5	95	117	77.5
30				13.0	96	123	120.7
31				13.5	95	126	115.6
32				14.0	103	136	111.8
33				14.5	106	144	132.1
34				24.0	103	130	111.8
35	*Nicotiana tabacum* (common tobacco)[2]	May 14	Indeterminate	10.0	18	30	101.6
36				12.0	19	30	114.3
37				13.0	18	30	114.3
38				14.0	18	30	111.8
39				24.0	18	32	106.7
40	*N. tabacum*[3]	June 7	Short day	10.0	...	16	129.5
41				12.0	...	73	162.6
42				13.0	...	73	154.9
43				14.0	...	88	167.6
44				24.0	...	90	149.9
45	*Oenothera speciosa* (white evening primrose)	April 16	Indeterminate	10.0	15	37	.....
46				12.0	13	35	.....
47				12.5	13	36	14.0
48				13.0	15	50	25.4
49				13.5	15	10	22.9
50				14.0	15	37	22.9
51				14.5	15	40	22.9
52				24.0	15	41	22.9
53	*Phaseolus coccineus* (scarlet runner bean)	May 21	Indeterminate	10.0	13	55	66.0
54				12.0	14	22	53.3
55				12.5	14	21	78.7
56				13.0	14	22	78.7
57				13.5	14	25	116.8
58				14.0	14	28	167.6
59				14.5	20	28	116.8
60				24.0	14	32	142.2
61	*Salix humilis* (prairie willow)	April 10	Short day	10.0	68	...	.....
62				12.0	55	...	.....
63				12.5	60	88	55.9
64				13.0	61	...	.....
65				13.5	61	...	.....
66				14.0	61	76	.....

/2/ Extra Early variety. /3/ Maryland Mammoth variety.

Contributor: Williams, Bert C.

Reference: Garner, W. W., and H. A. Allard. 1940. U.S. Dept. Agr. Tech. Bull. 727.

122. PHOTOPERIOD, WITH TEMPERATURE INTERACTIONS, FOR FLOWERING: ANGIOSPERMS

Varietal differences account for multiple photoperiodic classifications (column B); the common classification has been given priority in listing. Classification is followed in parentheses by the light period for flowering (>12 hr should be interpreted as 12 hours or more, <12 hr as up to 12 hours). **Temperature Interactions** (column C): Th = photoperiodic response occurring at relatively high temperatures (plant may also flower at other day lengths at lower temperatures), or reproductive development promoted by high temperatures during photoperiodic induction; Tl = photoperiodic response occurring at relatively low temperatures (plant may also flower at other day lengths at higher temperatures), or reproductive development promoted by low temperatures during photoperiodic induction; Tp = thermoperiodic (i.e., development affected by alternation of temperature between day and night periods); Tq = quantitative effect of temperature on critical day length (i.e., an increase in temperature lowers the minimum limits for long-day plants and raises the maximum limits for short-day plants), or on the degree of photoperiodic response; Ve = vernalization essential for complete reproductive development (or other low-temperature preconditioning of embryo plants, seedlings, buds, or plants), prior to photoperiodic induction; Va = vernalization not essential but promotes reproductive development; Vo = vernalization not effective. For additional information, consult references 5, 15, 30, 35, 45, and 54.

	Species (Common Name)	Photoperiodic Class and Light Period	Temperature Interactions	Reference
	(A)	(B)	(C)	(D)
	Monocotyledoneae			
1	*Allium cepa* (garden onion)	Long day favorable; short day favorable; day neutral	Tl	24,31,46
2	*Avena sativa* (common oat)	Long day required (>9 hr)	Tl; Va (for winter varieties); Vo (for spring varieties)	24
	Hordeum vulgare (barley)			
3	Spring	Long day favorable	Vo	40,41
4	Winter	Long day required (>12 hr)	Va (7°-9°C)	12,24
	Oryza sativa (rice)			
5	Summer	Day neutral	Th	47,48
6	Winter	Short day required (<12 hr)	Th	47,48
7	*Phleum pratense* (timothy)	Long day required (>12 hr)	....	3,52
8	*Poa pratensis* (Kentucky bluegrass)	Long day favorable	Th; Tl (day neutral or short day favorable); Ve	3,37,42,49
	Triticum aestivum (wheat)			
9	Spring	Long day favorable	Vo	24,33,34,55
10	Winter	Long day required (>12 hr)[1]	Va	24,33,34,55
11	*Zea mays* (corn)	Day neutral; short day required	....	25,32
	Dicotyledoneae			
12	*Antirrhinum majus* (snapdragon)	Long day favorable	Th; Tl (day neutral)	29,39
13	*Beta saccharifera* (sugar beet)	Long day required	Tl (7°-9°C); Ve	22
14	*B. vulgaris* (common beet)	Long day favorable	Th; Tl (long day required)	41
15	*Capsicum frutescens* (bush red pepper)	Day neutral; short day favorable	Tp	14,18,20
16	*Chrysanthemum maximum* (Pyrenees chrysanthemum)	Long day required	....	41
17	*Cucumis sativus* (cucumber)	Day neutral	....	16,51
18	*Daucus carota* (carrot)	Day neutral	Ve (4°-10°C)	44
19	*Digitalis purpurea* (common foxglove)	Long day favorable	Ve	8
20	*Fagopyrum esculentum* (buckwheat)	Day neutral	....	6,24
21	*Fragaria chiloensis* (chiloe strawberry)	Short day required (<10 hr)[1]	Tq	17,26
22	Everbearing	Long day favorable; day neutral	....	17
23	*Glycine soja* (soybean)	Short day required to short day favorable	Th; Tq	11,23,36
24	*Gossypium hirsutum* (upland cotton)	Day neutral; short day favorable	Tq	10,28
25	*Helianthus annuus* (common sunflower)	Short day favorable; day neutral	....	19
26	*Ilex aquifolium* (English holly)	Day neutral	....	43
27	*Ipomoea batatas* (sweet potato)	Short day required; short day favorable	....	32
28	*Lactuca sativa* (lettuce)	Long day favorable	Th; Tl (day neutral)	7,13,50
29	*Lycopersicon esculentum* (tomato)	Day neutral; long day favorable; short day favorable	Tp	1,53

/1/ Data applicable to most varieties.

continued

122. PHOTOPERIOD, WITH TEMPERATURE INTERACTIONS, FOR FLOWERING: ANGIOSPERMS

	Species (Common Name)	Photoperiodic Class and Light Period	Temperature Interactions	Reference
	(A)	(B)	(C)	(D)
	Dicotyledoneae			
30	*Medicago sativa* (alfalfa)	Long day favorable	Th; Tl (day neutral)[2]	42
31	*Nicotiana tabacum* (common tobacco)	Day neutral[1]	....	23
32	Common tobacco (Havana)	Long day favorable	....	41
33	Common tobacco (Maryland Mammoth)	Short day required (<14 hr)	Th; <13°C (day neutral)	23,42
34	*Oenothera biennis* (common evening primrose)	Long day favorable	Tl	42
35	*Phaseolus vulgaris* (kidney bean)	Day neutral; short day required[3]	....	4,23,32
36	*Phlox paniculata* (summer phlox)	Long day required	Th	41
37	*Pisum sativum* (garden pea)	Day neutral; long day favorable	....	9,42
38	*Raphanus sativus* (garden radish)	Long day required	....	23,38
39	*Rhododendron* sp. (rhododendron)	Day neutral	....	43
40	*Solanum tuberosum* (potato)	Long day favorable; short day favorable; day neutral	....	2,24,27
41	*Trifolium pratense*[4] (red clover)	Long day required (>12 hr)	....	52
42	*Vicia faba* (broad bean)	Day neutral	Va	21

/1/ Data applicable to most varieties. /2/ Vegetative in warm nights. /3/ Photoperiod influences fruit development, but floral initiation is not affected. /4/ English Montgomery variety; for American Medium, long day favorable (>9 hr).

Contributors: (a) Greulach, Victor A., (b) Cooper, J. P., and Calder, D. M., (c) Roberts, R. H., and Struckmeyer, Burdean E., (d) Hagen, Charles W., Jr.

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continued

122. PHOTOPERIOD, WITH TEMPERATURE INTERACTIONS, FOR FLOWERING: ANGIOSPERMS

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123. FACTORS AFFECTING PROTOPLASMIC STREAMING: PLANTS

Protoplasmic streaming as considered in this table includes shuttle-type flow of protoplasm in slime molds, protoplasmic streaming within rigid cell walls of Algae, and cyclosis in Monocotyledoneae. Many techniques were used to study streaming rates, and the results vary according to the methods and conditions of measurement. Values were interpolated where necessary from graphic and tabular data in the literature.

PART I. TEMPERATURE

	Species (Common Name)	Rate of Streaming, μ/sec 5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
	Algae									
1	*Chara foetida* (stonewort)	20.4	25.6	37.6	41.8	51.5	76.3	92.7	71.5	4
2		11.2	24.5	40.9	56.2	74.4	90.0			3
3	*Nitella* sp. (nitella)	10.5	15.3	20.0	26.7	34.3	43.3	47.3	37.0	2
4	*N. mucronata* (nitella)	12.7	28.0	41.2	59.6	75.3	96.2	109.1		3
	Monocotyledoneae									
5	*Elodea canadensis* (Canada waterweed)	4.8	7.7	8.8	10.5	11.5	13.3	16.7	0	4
6	*Vallisneria spiralis* (spiral wild celery)	4.7	8.7	15.1	20.0	26.3	31.2	38.5		4
	Avena sp. (oat), coleoptile									
7	90 hr old	3.4	4.8	7.0	8.2	8.3	8.5			1
8	200 hr old	3.6	5.7	7.9	10.4	12.8	15.8			

Contributor: Olson, Rodney A.

References: [1] Bottelier, H. P. 1934. Rec. Trav. Botan. Neerl. 31:474. [2] Ganong, W. F. 1908. A laboratory course in plant physiology. Ed. 2. H. Holt, New York. [3] Lambers, M. H. R. 1926. Dissertation. Utrecht Univ., Netherlands. [4] Velten, W. 1876. Flora (Jena) 59:209.

Part II. SUDDEN CHANGES OF TEMPERATURE

R_0 (column B) = average streaming rate (μ/sec) at initial temperature.

	Initial Temp., °C	R_0	Final[1] Temp., °C	Rate of Streaming, μ/sec, at Specified Interval in minutes 20	30	40	50	60	70	80	90	100	110	120	Temperature Sensitivity[2]
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)
	***Nitella flexilis* (Pliant Nitella)**														
1	13.8	28.5	24.5	55	55	55	55	55	55	55	55	55	55	55	
2	13.8	28.5	31.5	80	80	80	80	80	80	80	80	80	80	80	
3	13.8	28.5	37.5	99	99	99	99	99	99	99	99	99	99	99	
4	19	55	12.8	36	36	36	36	36	36	36	36	36	36	36	
5	22	62.5	12.8	36	36	36	36	36	36	36	36	36	36	36	$\frac{100}{12} = 8.3$
6	24.3	70	12.8	36	36	36	36	36	36	36	36	36	36	36	
7	26	74	12.8	24	28	32	34	36	36	36	36	36	36	36	

/1/ Temperature prevailing during test. /2/ Equals 100 divided by the maximum temperature difference (at which no rate lag occurs).

continued

123. FACTORS AFFECTING PROTOPLASMIC STREAMING: PLANTS

Part II. SUDDEN CHANGES OF TEMPERATURE

	Initial Temp., °C	R_0	Final[1] Temp., °C	Rate of Streaming, μ/sec, at Specified Interval in minutes: 20	30	40	50	60	70	80	90	100	110	120	Temperature Sensitivity[2]
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)
	Nitella flexilis **(Pliant Nitella)**														
8	25	86	20	71	71	71	71	71	71	71	71	71	71	71	
9	27.5	93	20	64	68	69	70	71	71	71	71	71	71	71	$\frac{100}{6} = 16.6$
10	30	100	20	62	65	66	68	69	70	71	71	71	71	71	
11	35	114	20	45	50	52	54	56	58	60	62	63	64	65	
12	30	100	25	83	83	83	83	83	83	83	83	83	83	83	
13	32.5	104	25	83	83	83	83	83	83	83	83	83	83	83	
14	33	106	25	83	83	83	83	83	83	83	83	83	83	83	$\frac{100}{9} = 11.1$
15	35	113	25	77	80	82	82	83	83	83	83	83	83	83	
16	38.5	125	25	71	74	76	77	78	80	81	81	82	83	83	
17	40	131	25	25	40	48	54	58	62	65	68	70	71	72	
	Avena **(Oat) Coleoptile**														
18	21	12	13	6.2	6.4	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	
19	24	12.8	13	0.1	2.1	3.2	4.4	5.1	5.8	6.3	6.9	7.5	7.6	7.6	$\frac{100}{7.5} = 13$
20	28	12.6	13	0	0.4	1.2	2.6	4.5	5.8	6.6	7.3	7.7	7.7	7.7	
21	25	11	21	9.1	9.9	10.2	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	
22	27	10	21	4.5	9.9	11.9	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	$\frac{100}{3.5} = 30$
23	36	3.4	21	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.2	0.4	1.4	3.6	

/1/ Temperature prevailing during test. /2/ Equals 100 divided by the maximum temperature difference (at which no rate lag occurs).

Contributor: Olson, Rodney A.

Reference: Romijn, G. 1931. Koninkl. Ned. Akad. Wetensc..ap. Proc., C, 34:1.

Part III. LIGHT INTENSITY: AVENA COLEOPTILE

Nonchlorophyll-containing cells of *Avena* coleoptile were observed in the orange-red, phototropically inactive spectral region after exposure to various doses of blue light (4,360 Å), at 23°C. Data show the fitness of the "product rule" (intensity x time), as well as the effect of total energy (dosage). **Reaction** (column D) = the algebraic sum of percent departures from normal rate; negative values indicate a decrease in streaming, and positive values, an increase.

	Dosage[1] ergs per sq cm	Illumination: Intensity ergs per sq cm per sec	Illumination: Time sec	Reaction[2]
	(A)	(B)	(C)	(D)
1	10	2	5	-29
2	12	23.6	0.5	-54
3	20	2	10	-49
4	20	5	4	-67
5	22	11	2	-74
6	24	23.6	1	-75
7	40	2	20	-72
8	47	23.6	2	-87
9	55	11	5	-70
10	66	11	6	-74
11	80	2	40	-91
12	88	11	8	-78
13	94	23.6	4	-77
14	110	11	10	-118
15	118	23.6	5	-92
16	120	2	60	-112
17	142	23.6	6	-97
18	160	5	32	-103
19	180	2	90	-160
20	189	23.6	8	-136
21	220	11	20	-169
22	236	23.6	10	-105
23	240	2	120	-118
24	360	2	180	-104
25	378	23.6	16	-81
26	440	11	40	-84
27	472	23.6	20	-54
28	480	2	240	-107
29	600	5	120	-69
30	660	11	60	-22
31	746	23.6	32	-15
32	944	23.6	40	+32
33	1,320	11	120	+132
34	1,420	23.6	60	+42
35	2,100	23.6	90	+28
36	2,800	23.6	120	+26
37	4,200	23.6	180	+4

/1/ Intensity (column B) x time (column C). /2/ Average of 1-20 separate experiments for each energy value.

Contributor: Olson, Rodney A.

Reference: Bottelier, H. P. 1934. Rec. Trav. Botan. Neerl. 31:474.

continued

123. FACTORS AFFECTING PROTOPLASMIC STREAMING: PLANTS

Part IV. VARIOUS WAVELENGTHS: AVENA COLEOPTILE

Reaction (column C) = the algebraic average of percent departures from normal rate; negative values indicate a decrease in streaming, and positive values, an increase.

	Wavelength Å	Dosage[1]	Reaction	Equivalent Energy[2]	Spectral Sensitivity
	(A)	(B)	(C)	(D)	(E)
1	3,660	270	-46	16	6
2		760	-85	90	12
3	4,360	*See* Part III			
4	4,550	21	-15	7	33
5		67	-33	13	20
6		190	-90	95	50
7	5,460	230	-16	7	3
8		240	-15	7	3
9		1,790	-60	30	1.7
10	5,780	9,000	+1		<1
11	6,200	*See* Fn. 3	+1		<1

/1/ Intensity x time. /2/ Equivalent energy required at 4,360 Å for comparable effect. /3/ Approximately 70 ergs per sq cm per sec.

Contributor: Olson, Rodney A.

Reference: Bottelier, H. P. 1934. Rec. Trav. Botan. Neerl. 31:474.

Part V. OXYGEN

	Material	Temp. °C	O_2 Concentration % Saturation	O_2 Concentration ml/L	Streaming Rate μ/sec	% of Normal Rate: Streaming	% of Normal Rate: Respiration	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
1	*Physarum polycephalum*	22	21	6.27	Normal	100	100	1
2			2.4	0.72	Normal	....	60	1
3			1.0	0.30	Reduced	....	30	1
4			0.3	0.08	Reduced	....	9	1
5			0.1	0.03	Reduced	....	3	1
6			0	0	Reduced	0	0	1
	Avena sp., coleoptile							
7	96 hr old	21	100	30.4	9.9	99	...	2
8		26	100	27.8	10.1	132	...	2
9		21	21	6.32	10.0	100	...	2
10		26	21	5.85	10.1	100	...	2
11	260 hr old	21	21	6.32	10.2	100	...	2
12		26	21	5.85	13.4	100	...	2
13		21	4	1.23	9.0	88	...	2
14		26	4	1.02	9.1	68	...	2
15	80 hr old	25	10.8-14.6[1]	3.1-4.1	....	100	100[2]	3
16			14.6[1]-21.0	4.1-5.7	....	....	50[2]	3
17	95 hr old	25	10.8-18.2[1]	3.1-5.3	....	100	100[2]	3
18			18.8[1]-21.0	5.3-5.7	....	....	50[2]	3
19	130 hr old	25	11.6-12.4[1]	3.2-3.5	....	100	100[2]	3
20			12[1]-21	3.5-5.7	....	....	50[2]	3

/1/ Critical O_2 tension. /2/ Rates are uniform within indicated O_2 ranges; a sharp change in rate occurs at the critical O_2 tension.

Contributor: Olson, Rodney A.

References: [1] Allen, P. J., and W. Price. 1950. Am. J. Botany 37:393. [2] Bottelier, H. P. 1935. Rec. Trav. Botan. Neerl. 32:287. [3] DuBuy, H. G., and R. A. Olson. 1940. Am. J. Botany 27:392.

124. FACTORS AFFECTING TRANSPIRATION RATES: ANGIOSPERMS

Part I. VARIOUS CONDITIONS

Water loss was calculated from data obtained in experiments using intact plants growing in soil, unless otherwise stated. **Specifications** (columns B and C): SM = soil moisture; SWC = wilting coefficient of soil; EA = evaporation from atmometer; AT = air temperature; RH = relative humidity; WV = wind velocity; SS = possible sunshine; ES = evaporation from free-water surface; ST = soil temperature; WHC = soil moisture in percent of water-holding capacity on dry-weight basis; LIE = light intensity energy; LI = light intensity; SD = saturation deficit of air; RI = total radiation intensity.

	Species (Common Name)	Specifications: Constants	Specifications: Variables	Water Loss mg/sq cm leaf surface/hr	Reference
	(A)	(B)	(C)	(D)	(E)
1	*Aeonium haworthi* (Haworth aeonium)	1 plant	WV = 1,100 cm/sec	0.58	12
2			WV = 570 cm/sec	0.21	
3	*Ananas comosus* (pineapple)[1]	19 plants; 1.5 mo old	Hr ending 3 p.m.; AT = 31°C; RH = 59%; WV = 128 cm/sec; SS = 100%; EA = 3 cc/hr	1.96	5
4			Hr ending 4 a.m.; AT = 24°C; RH = 85%; WV = 6 cm/sec; SS = 0; EA = 0.5 cc/hr	0.03	
5	*Bellis perennis* (English daisy)	3 plants; several yr old; AT = 20°-22°C; RH = 40-65%; WV = 90 cm/sec; ES = 0.0209 g/sq cm	Continental type plants	15.3	13
6			Maritime type plants	12.2	
7	*Capsicum frutescens* (bush red pepper)	6 plants; 8 inches high	WHC = 50	3.5	3
8			WHC = 25	1.1	
9	*Citrus limon* (lemon)	3 plants; 6± mo old	ST = 31°C	4.9	4
10			ST = 19°C	3.5	
11	*C. paradisi* (grapefruit)	3 plants; 6± mo old	ST = 27°C	4.6	4
12			ST = 35°C	3.1	
13	*Euphorbia capitellata* (head euphorbia)	1 plant	10 a.m.-2 p.m.; ES = 0.050 g/sq cm	4.5	8
14			9:30 p.m.-7 a.m.; ES = 0.010 g/sq cm	0.1	
15	*Gossypium herbaceum* (Levant cotton)	6± wk old	Untreated soil of low salt concentration	15.0	10
16			0.8% calcium nitrate added to soil	1.6	
17	*Helianthus annuus* (common sunflower)	5 plants; few wk old	Hr ending 1 p.m.; RI = 0.960 cal/sq cm/min; AT = 23.9°C; RH = 42%; WV = 215 cm/sec	23.8	9
18			Hr ending 8 a.m.; RI = 0.223 cal/sq cm/min; AT = 13.3°C; RH = 69%; WV = 4.5 cm/sec	2.7	
19		4 plants; 6 wk old; AT = 26.7°C; RH = 27%; WV = 19.0 cm/sec	ST = 37.8°C	27.2	2
20			ST = 2.2°C	4.7	
21	*Hieracium pilosella* (mouse-ear hawkweed)	1 plant; LI = 30,000 lux	Hr ending 7 a.m.; AT = 19.2°C; SD = 7.1%	5.5	6
22			Hr ending 4 p.m.; AT = 21.1°C; SD = 8.1%	3.5	
23	*Lychnis dioica* (red campion)	3 plants; several yr old; AT = 19.5°-20.5°C; RH = 40-65%; WV = 90 cm/sec; ES = 0.0285 g/sq cm	Beech-forest type plants	10.5	13
24			Maritime type plants	6.3	
25	*Malus pumila* (common apple)	2 plants; 11 yr old	Grown with straw mulch	17.2	3
26			Grown in sod without mulch	14.3	
27	*Nicotiana tabacum* (common tobacco)	9 plants; 3-4 leaves; RH = 68%	Exposed to visible light: LIE = 0.72 cal/sq cm/min; AT = 36.7°-37.8°C	36.4	1
28			Exposed to infrared light: LIE = 0.65 cal/sq cm/min; AT = 22.8°-25.6°C	5.6	
29	*Rumex acetosa* (garden sorrel)	3 plants; several yr old; AT = 17°-24°C; RH = 40-65%; WV = 90 cm/sec; ES = 0.0334 g/sq cm	Alpine type plants	28.0	13
30			Lowland type plants	11.6	
31	*Triticum aestivum* (wheat)	6 plants; 1+ mo old	Grown in good loam soil	2.1	7
32			Grown in poor soil	1.1	
33	*Veronica beccabunga* (beccabunga speedwell)	2 plants; LI = 30,000 lux	Hr ending 2 p.m.; AT = 21.0°C; SD = 10.0%	6.75	6
34			Hr ending 6 p.m.; AT = 21.5°C; SD = 10.6%	3.17	
35	*Zea mays* (corn)	1 plant; 2 ft high; 9 fully, 7 partly unfolded leaves; SM = 22% of dry wt; SWC = 15.1	2-hr periods ending 3 p.m.; EA = 7.7 cc/hr	28.29	11
36			2-hr periods ending 7 a.m.; EA = 0.8 cc/hr	0.86	

/1/ Growing in nutrient solution.

continued

124. FACTORS AFFECTING TRANSPIRATION RATES: ANGIOSPERMS

Part I. VARIOUS CONDITIONS

Contributor: Krauss, Beatrice

References: [1] Arthur, J. M., and W. D. Stewart. 1933. Contrib. Boyce Thompson Inst. 5:491. [2] Clements, F. E., and E. V. Martin. 1934. Plant Physiol. 9:621. [3] Cullinen, F. P. 1920. Proc. Am. Soc. Hort. Sci. 17:237. [4] Haas, A. R. C. 1936. Calif. Citrograph 21:479. [5] Krauss, B. H. 1930. M.S. Thesis. Univ. Hawaii, Honolulu. p. 82. [6] Lachenmeier, J. 1932. Jahrb. Wiss. Botan. 76:825. [7] Livingston, B. E. 1905. Botan. Gaz. 40:189. [8] Livingston, B. E. 1906. Carnegie Inst. Wash. Publ. 50:45. [9] Martin, E. V. 1935. Plant Physiol. 10:344. [10] Meyer, B. S. 1931. Am. J. Botany 18:85. [11] Miller, E. C. 1918. J. Agr. Res. 13:585. [12] Seybold, A. 1929. Die physikalische Komponente der pflanzlichen Transpiration. J. Springer, Berlin. p. 91. [13] Turesson, G. 1928. Hereditas 11:199.

Part II. VARIATION IN SOIL CONDITIONS: CORN

	Soil Condition	Leaf Area per Plant sq cm	Dry Matter per Plant, g		Water Loss		
			Grain	Total	per Plant kg	per Gram Grain, g[1]	per Gram Dry Matter, g[1]
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	8-Year Average						
	No manure added						
1	Infertile	2,948	17	72	38.3	8,263	531
2	Intermediate	3,573	26	108	51.3	2,485	489
3	Fertile	4,612	74	213	77.4	1,100	368
	2.4 lb manure added/plant						
4	Infertile	4,244	52	180	68.9	1,518	396
5	Intermediate	4,638	67	207	75.6	1,173	369
6	Fertile	5,121	108	289	94.2	879	327
	3-Year Average						
7	Too dry (50% saturation)	6,818	165	379	105.5	695	289
8	Favorable (70% saturation)	8,056	230	522	162.2	716	316
9	Too wet (95% saturation)	7,031	168	422	142.1	854	341

/1/ Average of ratios.

Contributor: Kiesselbach, T. A.

Reference: Kiesselbach, T. A. 1929. Proc. Intern. Congr. Plant Sci., 1st, Ithaca, 1926, 1:87.

Part III. DIURNAL VARIATION: CORN

	Period	Temp. °C	RH[1] %	Wind mi/hr	Water Loss per Plant[2] g	Water Evaporation[3] g
	(A)	(B)	(C)	(D)	(E)	(F)
1	8 a.m.	23.1	80	6	84	4.8
2	9	25.5	73	7	111	7.7
3	10	27.6	67	8	167	11.6
4	11	29.3	63	8	215	15.0
5	12	30.8	58	9	279	19.2
6	1 p.m.	31.9	55	9	329	23.7
7	2	32.7	53	9	356	24.5
8	3	32.9	52	9	354	23.8
9	4 p.m.	32.8	50	9	343	22.2
10	5	32.2	51	8	294	18.5
11	6	31.2	53	8	217	14.1
12	7	28.4	58	7	132	10.2
13	8	27.6	64	7	64	6.4
14	Day average	29.8	59.8	8	226	15.5
15	Night average	22.7	81.5	6	16	2.3

/1/ Mean relative humidity. /2/ Water transpired from one plant. /3/ From 36 square inches free-water surface, under identical conditions.

continued

124. FACTORS AFFECTING TRANSPIRATION RATES: ANGIOSPERMS

Part III. DIURNAL VARIATION: CORN

Contributor: Kiesselbach, T. A.

Reference: Kiesselbach, T. A. 1916. Nebraska Univ. Agr. Expt. Sta. Res. Bull. 6.

Part IV. ANNUAL VARIATION

Averages (column I) are comparable only when derived from data for identical years.

	Species	Common Name	Seasonal Water Requirement, g[1]						
			1912	1913	1914	1915	1916	1917	Average
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
			South Dakota [1]						
1	*Medicago sativa*	Alfalfa	735	735	1,038	696	673	866	790
2	*Setaria italica*	Foxtail millet	239	293	311	171	233	278	254
3	*Sorghum vulgare sudanense*	Sudan grass	....	....	.....	272	314	344	310
4	*Triticum aestivum*	Wheat	463	436	528	333	352	487	433
			Colorado [2]						
5	*Amaranthus retroflexus*	Redroot amaranth	....	320	306	229	340	307	300
6	*Avena sativa*	Common oat	449	617	615	445	809	636	595
7	*Bouteloua gracilis*	Blue grama	....	....	389	312	336	290	332
8	*Gossypium hirsutum*	Upland cotton	488	657	574	443	612	522	549
9	*Hordeum vulgare*	Barley	443	....	501	404	664	522	507
10	*Medicago sativa*	Alfalfa	657	834	[illegible]	695	1,047	822	824
11	*Secale cereale*	Rye	....	....	622	469	800	625	629
12	*Setaria italica*	Foxtail millet	187	286	295	202	367	284	273
13	*Sorghum vulgare sudanense*	Sudan grass	....	....	394	260	426	378	365
14	*Triticum aestivum*	Wheat	394	496	518	405	636	471	487
15	*Vigna sinensis*	Cowpea	....	571	659	413	767	481	573
16	*Zea mays*	Corn	280	399	368	253	495	346	357

[1] Ratio of weight of water transpired to weight of dry matter produced.

Contributor: Bailey, Lowell F.

References: [1] Dillman, A. C. 1931. J. Agr. Res. 42:187. [2] Shantz, H. L., and L. N. Piemeisel. 1927. Ibid. 34:1093.

125. FACTORS AFFECTING OSMOTIC POTENTIAL: VASCULAR PLANTS

Osmotic pressure, a direct function of cell sap concentration, causes movement of water into roots and throughout plant. Osmotic potential is the maximum pressure that could be developed under ideal conditions. Values are given in atmospheres.

Part I. SPECIES VARIATION: LEAVES

	Species (Common Name)	Osmotic Potential	Reference
	(A)	(B)	(C)
1	*Acer rubrum* (red maple)	11.2-16.7	3
2	*Arctium minus* (smaller burdock)	9.8-13.7	3
3	*Beta vulgaris* (common beet)	14.0	1
4	*Betula lutea* (yellow birch)	12.6-16.0	3
5	*Chenopodium album* (lamb's-quarters)	13.2	3
6	*Citrus limon* (lemon)	15.1-21.4	3
7	*Cornus florida* (flowering dogwood)	11.1-16.7	3
8	*Fraxinus americana* (white ash)	16.4	3
9	*Galium aparine* (catchweed bedstraw)	9.6	3
10	*Gossypium* sp. (cotton)	22.0	1
11	*Helianthus annuus* (common sunflower)	13.8-18.0	3
12	*Impatiens biflora* (spotted snapweed)	4.6-8.4	3
13	*Iris germanica* (German iris)	13.1	2
14	*Juglans nigra* (black walnut)	12.6-18.3	3
15	*Liquidambar styraciflua* (American sweet gum)	13.3-15.5	3
16	*Liriodendron tulipifera* (yellow poplar)	11.3-16.4	3
17	*Osmunda cinnamomea* (cinnamon fern)	9.8	3

continued

125. FACTORS AFFECTING OSMOTIC POTENTIAL: VASCULAR PLANTS

Part I. SPECIES VARIATION: LEAVES

	Species (Common Name)	Osmotic Potential	Reference
	(A)	(B)	(C)
18	*Phytolacca americana* (pokeberry)	8.5-9.5	3
19	*Picea engelmanni* (Engelmann spruce)	11.5-23.5	3
20	*Pinus* spp. (pine)	16.0-18.4	3
21	*Pisum sativum* (garden pea)	9.2	5
22	*Platanus occidentalis* (American sycamore)	13.5	3
23	*Poa pratensis* (Kentucky bluegrass)	12.6-18.6	4
24	*Populus alba* (white poplar)	19.7-20.1	3
25	*P. deltoides* (eastern poplar)	21.3	4
26	*Quercus alba* (white oak)	15.8-18.4	3
27	*Q. coccinea* (scarlet oak)	19.1	3
28	*Robinia pseudoacacia* (black locust)	9.8-14.3	3
29	*Salix alba* (white willow)	12.3-14.2	3
30	*Solidago* sp. (goldenrod)	10.3	3
31	*Taraxacum officinale* (dandelion)	8.5-10.8	3
32	*Typha latifolia* (cattail)	9.7-11.8	3
33	*Verbascum thapsus* (flannel mullein)	8.0-10.0	3
34	*Xanthium* sp. (cocklebur)	8.4-10.7	3

Contributors: (a) Anderson, Donald B., (b) Howell, Robert W.

References: [1] Bennet-Clark, T. A., and D. Bexon. 1940. New Phytologist 39:337. [2] Dixon, H. H. 1914. Transpiration and the ascent of sap in plants. Macmillan, New York. [3] Harris, J. A. 1934. The physicochemical properties of plant saps in relation to phytogeography. Univ. Minnesota Press, Minneapolis. [4] Meyer, B. S., and D. B. Anderson. 1939. Plant physiology. Van Nostrand, New York. [5] Thatcher, F. S. 1939. Am. J. Botany 26:449.

Part II. PHYSICAL AND ENVIRONMENTAL VARIATION

	Species (Common Name)	Plant Part	Specification	Osmotic Potential	Reference
	(A)	(B)	(C)	(D)	(E)
	Temperature				
1	*Potamog*	aves	0°C	14.3	1
2	*crispus*		13°C	13.5	
3	(curly pond-		23°C	12.7	
4	weed)		30°C	11.1	
	Height on Tree				
5	*Juglans nigra*	Leaves	2.4 cm	16.8	2
6	(black wal-		6.3 cm	17.8	
7	nut)		9.7 cm	18.2	
8			11.6 cm	17.2	
9			13.4 cm	18.3	
10			15.9 cm	18.3	
	Distance from Growing Point				
11	*Vicia faba*	Root	1.5 mm	11.3	7
12	(broad bean)		3.0 mm	11.7	
13			5.0 mm	12.7	
14			8.0 mm	9.8	
	Diurnal				
15	*Ambrosia trifida* (giant	Top leaf	6 a.m.	12.5	3
16	ragweed)		10 a.m.	15.3	
17			2 p.m.	17.4	
18			5 p.m.	16.5	
19			8 p.m.	16.3	
20		1st leaf from top	6 a.m.	12.5	
21			10 a.m.	15.6	
22			2 p.m.	17.2	
23			5 p.m.	15.7	
24			8 p.m.	14.9	
25	*Ambrosia trifida* (giant	2nd leaf from top	6 a.m.	12.9	3
26	ragweed)		10 a.m.	15.0	
27			2 p.m.	17.1	
28			5 p.m.	15.7	
29			8 p.m.	14.9	
30		Lowest leaf	6 a.m.	10.1	
31			10 a.m.	13.0	
32			2 p.m.	15.9	
33			5 p.m.	14.3	
34			8 p.m.	14.0	
35	*Andropogon scoparius*	Shoots[1]	12 noon	23.0	10
36	(little blue-		2 p.m.	25.0	
37	stem)		4 p.m.	27.0	
38			6 p.m.	26.0	
39			8 p.m.	21.5	
40			10 p.m.	20.5	
41			4 a.m.	21.0	
42			8 a.m.	25.0	
43	*Rumex patientia* (patience	Leaf guard cells	8:30 a.m.	16.6	9
44	dock)		1:30 p.m.	21.0	
45			3:30 p.m.	20.2	
46			7:30 p.m.	13.2	
47		Leaf subsidiary cells	8:30 a.m.	16.6	
48			1:30 p.m.	16.6	
49			3:30 p.m.	17.8	
50			7:30 p.m.	15.5	
51		Leaf epidermal cells	8:30 a.m.	14.4	
52			1:30 p.m.	14.4	
53			3:30 p.m.	14.4	
54			7:30 p.m.	13.2	

/1/ During extreme drought.

continued

125. FACTORS AFFECTING OSMOTIC POTENTIAL: VASCULAR PLANTS

Part II. PHYSICAL AND ENVIRONMENTAL VARIATION

	Species (Common Name)	Plant Part	Specification	Osmotic Potential	Reference
	(A)	(B)	(C)	(D)	(E)
	Seasonal				
55	*Linnaea borealis* (twinflower)		Oct	19.6	5
56			Dec	25.0	
57			Mar	25.6	
58			May	14.3	
59	*Picea glauca* (white spruce)		Oct	17.1	5
60			Dec	20.3	
61			Jan	20.0	
62			Mar	24.9	
63			Apr	20.1	
64			May	21.0	
65			June	19.7	
66	*Populus tremuloides* (quaking aspen)		Oct	15.0	5
67			Dec	16.8	
68			Jan	16.2	
69			Feb	13.7	
70			Mar	17.0	
71			May	10.6	
72	*Pyrola rotundifolia* (European pyrola)		Dec	24.6	5
73			Feb	23.9	
74			Apr	17.2	
75			June	12.6	
	Soil Water Content				
76	*Zea mays* (corn)	Shoots	31%	22.1	4
77			16%	24.4	
78			14%	25.0	
79			11%	26.5	
80		Roots	31%	5.9	
81			16%	7.8	
82			14%	9.2	
83			11%	12.0	
	Osmotic Concentration of Soil Solution				
84	*Zea mays* (corn)	Shoots	1.2 atm	6.2	6
85			2.0 atm	7.1	
86			3.4 atm	7.0	
87			5.0 atm	7.2	
88			7.2 atm	7.3	
89		Roots	1.2 atm	4.6	
90			2.0 atm	5.5	
91			3.4 atm	6.6	
92			5.0 atm	7.5	
93			7.2 atm	8.2	
	Age				
94	*Triticum aestivum* (wheat)	Entire plant	2 da	10.7	12
95			3 da	9.8	
96			4 da	8.0	
97			5 da	7.8	
98			6 da	7.1	
99			7 da	6.6	
100	*Triticum aestivum* (wheat)	Entire plant	8 da	6.0	12
101			9 da	5.4	
102			10 da	5.1	
103			13 da	4.9	
104			15 da	5.4	
105			25 da	6.0	
106		Shoots	10 da	6.56	
107			15 da	7.04	
108		Roots	10 da	3.06	
109			15 da	3.03	
	Tissue				
110	*Castanea sativa* (European chestnut)		Sieve-tubes	15.6-17.1	8
111		Roots	Cambium	9.7-11.0	
112			Wood	6.3	
113		Stems	Cambium	11.1-12.9	
114			Wood	7.5-11.8	
115	*Fagus* sp. (beech)	Leaves	Epidermis	15.0	11
116			Spongy parenchyma	22.4	
117			Palisade parenchyma	37.7	
118		Stems	Cambium	24.6	
119			Xylem parenchyma	36.6	
120			Wood lays	35.2	
121			Cortex	26.1	
122			Phloem parenchyma	22.5	
123	*Helleborus* sp. (hellebore)	Leaves	Epidermis	19.2	11
124			Spongy parenchyma	22.5	
125			Palisade parenchyma	32.9	
126		Stems	Cambium	21.9	
127			Xylem parenchyma	22.2	
128			Pith	20.6	
129			Cortex	20.8	
130	*Tradescantia* sp. (spiderwort)	Pulvini	Pith	6.5	7
131			Starch sheath	7.7	
132			Cortex	6.3	
133	*Urtica* sp. (nettle)	Leaves	Epidermis	18.8	11
134			Spongy parenchyma	24.7	
135			Palisade parenchyma	37.7	
136		Stems	Cambium	21.5	
137			Xylem parenchyma	23.0	
138			Pith	18.7	
139			Cortex	19.2	
140			Phloem parenchyma	20.4	

Contributors: (a) Levitt, J., (b) Howell, Robert W., (c) Yocum, L. Edwin

References: [1] Gamma, H. 1932. Protoplasma 16:489. [2] Harris, J. A., R. A. Gortner, and J. V. Lawrence. 1917. Bull. Torrey Botan. Club 44:267. [3] Herrick, E. M. 1933. Am. J. Botany 20:18. [4] Hibbard, R. P., and O. E. Harrington. 1916. Physiol. Res. 1:441. [5] Lewis, F. J., and G. M. Tuttle. 1920. Ann. Botany (London) 34:405. [6] McCool, M. M., and C. E. Miller. 1917. Soil Sci. 3:113. [7] Molz, F. J. 1926. Am. J. Botany 13:433.

continued

Part II. PHYSICAL AND ENVIRONMENTAL VARIATION

[8] Pfeiffer, M. 1933. Planta 19:272. [9] Sayre, J. D. 1926. Ohio J. Sci. 26:233. [10] Stoddart, L. A. 1935. Plant Physiol. 10:661. [11] Ursprung, A., and G. Blum. 1916. Ber. Deut. Botan. Ges. 34:88. [12] Yocum, L. E. 1925. J. Agr. Res. 31:727.

Part III. VARIATION IN DEPTH OF ROOTING

	Species	Common Name	Osmotic Potential								
			Apr 19	Apr 24	May 8	May 28	June 8	June 20	July 2	July 9	July 31
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
	Shallow-rooted Plants										
1	*Astragalus crassicarpus*	Ground plum milk vetch	10.9	13.2	15.4	18.7	....	....	....	....	....
2	*Koeleria cristata*	Prairie June grass	16.4	17.4	24.1	35.0	....	....	....	....	....
3	*Lomatium foeniculaceum*	Lomatium	11.5	14.6	16.1	20.0	....	....	....	....	....
	Moderately Deep-rooted Plants										
4	*Andropogon scoparius*	Little bluestem	8.1	9.6	9.9	25.3	18.1	17.4	31.3	....	....
5	*Helianthus rigidus*	Stiff sunflower	....	....	12.6	19.9	15.2	22.9	36.9	....	....
6	*Solidago glaberrima*	Goldenrod	....	12.0	....	12.8	14.3	16.8	....	....	....
	Deep-rooted Plants										
7	*Amorpha canescens*	Leadplant	....	11.6	13.1	20.8	16.2	15.1	17.2	20.0	22.1
8	*Baptisia leucophaea*	Plains wild indigo	8.6	10.8	12.0	14.8	16.0	16.7	17.3	....	....
9	*Psoralea tenuiflora*	Slim flower scurf pea	....	12.2	14.2	17.8	16.0	16.8	15.2	17.2	15.8

Contributor: Yocum, L. Edwin

Reference: Stoddart, L. A. 1935. Plant Physiol. 10:661.

Part IV. VARIATION IN HABITAT

	Habitat	Osmotic Potential	
		Woody Plants	Herbaceous Plants
	(A)	(B)	(C)
	Jamaica		
1	Ruinate	13	10
2	Ridge forest	12	9
3	Leeward ravines	11	8
4	Windward habitat	10	8
	Arizona		
5	Rocky slopes	22	16
6	Canyons	21	13
7	Arroyos	17	13
8	Bajada slopes	30	20
9	Salt spots	45	24

Contributor: Yocum, L. Edwin

Reference: Harris, J. A., and J. V. Lawrence. 1917. Am. J. Botany 4:268.

Part V. VARIATION IN ECOLOGIC GROUPS

	Plant Group	Osmotic Potential	Reference
	(A)	(B)	(C)
1	Summer ephemerals	8-42	4
2	Succulents and winter ephemerals	4-24	4
3	Xerophytes	14-57	4
4	Hydrophytes	8-13	1
5	Air leaves	18-21	2
	Hydrophytes		
6	Water leaves	8-9	2
7	Epiphytes	3-6	1
8	Halophytes	30-115	5
9	Parasites[1]	14-17	3
10	Hosts	11-14	3

/1/ *Phoradendron flavescens* (American mistletoe), 15.8; host, 11.6.

continued

125. FACTORS AFFECTING OSMOTIC POTENTIAL: VASCULAR PLANTS

Part V. VARIATION IN ECOLOGIC GROUPS

Contributor: Levitt, J.

References: [1] Gamma, H. 1932. Protoplasma 16:489. [2] Gessner, F. 1940. Ber. Deut. Botan. Ges. 58:2. [3] Harris, J. A. 1934. The physico-chemical properties of plant saps in relation to phytogeography. Univ. Minnesota Press, Minneapolis. [4] Huber, B. 1951. Fortschr. Botan. 13:227. [5] Zohary, M., and G. Orshansky. 1949. Palestine J. Botany, Jerusalem Ser., 4:177.

126. MAXIMUM PERMISSIBLE OCCUPATIONAL EXPOSURE TO RADIATION: MAN

Part I. DOSE EQUIVALENT TO BODY ORGANS

Values are the recommended permissible doses of ionizing radiation to the various organs of the body of the occupational worker, and are in addition to doses from medical and background exposure. The values apply to both external and internal exposure. The unit of dose equivalent used in this table is the rem. No. of rem = no. of rad x RBE x n. (Rad = unit of absorbed dose; 1 rad corresponds to 100 ergs/g of medium. RBE = relative biological effectiveness, i.e., ratio of absorbed dose, in rads, from reference X rays to the absorbed dose, in rads, from the given radiation field required to produce the same effect as the reference X rays. Reference X rays in most cases have been those from 200-250 kilovolts X-radiation or γ-radiation from Co^{60}. n = relative damage factor.) DE = dose equivalent.

	Body Organ	Maximum DE in Any 13 Wk[1] rem/13 wk	Average DE in 1 Yr[2] rem/yr	Accumulated DE for Ages >18 Yr[3] rem
	(A)	(B)	(C)	(D)
1	Total body	3	5	5(age-18)
2	Head and trunk	3	5	5(age-18)
3	Lenses of eyes	3	5	5(age-18)
4	Blood-forming organs	3	5	5(age-18)
5	Gonads	3	5	5(age-18)
6	Bone	10	30	30(age-18)
7	Skin	8-10	30	30(age-18)
8	Thyroid	8-10	30	30(age-18)
9	Feet, ankles, hands, & forearms	20-25	75	75(age-18)
10	Other single organs	4-5	15	15(age-18)

/1/ These values may be used for the accumulated short-term exposures in any 13-week interval. /2/ These values may be used for a planned emergency exposure. /3/ To determine accumulated dose equivalent, multiply value times age minus 18 years.

Contributor: Morgan, Karl Z.

Reference: Morgan, K. Z. 1963. Science 139:565.

Part II. TYPE OF RADIATION

All values in columns C and D may be increased by a factor of 6 if the exposure is primarily to the bone, skin, or thyroid. They may be increased by a factor of 3 if the exposure is limited to organs other than the eyes, gonads, or blood-forming organs.

	Type of Radiation	QF[1]	Average Exposure Rate[2] mrad/wk	Approximate Flux to Give a Maximum Permissible Exposure in an 8-Hour Day[3]
	(A)	(B)	(C)	(D)
1	X and γ rays	1	100	$\frac{1400}{E}$ photons per sq cm per sec in free air at 0°C (error <13% for E = 0.07-2 Mev)

/1/ Quality factor, a term used to express the modification of RBE due to LET (linear energy transfer of the radiation), n (relative damage factor), and other conditions. /2/ Permissible to eyes, gonads, and blood-forming organs (essentially total body exposure) of individuals 18 years or older. These values may be averaged over a year, provided the dose equivalent in any 13 weeks does not exceed 3 rem (rem = rad x QF). /3/ Rate based on a 20-mrem dose equivalent delivered to tissue in an 8-hour day (= 2.5 per QF mrad per hr). The rad in soft tissue is considered to correspond to an energy absorption of 100 ergs/g. Mev = one million electron volts.

continued

126. MAXIMUM PERMISSIBLE OCCUPATIONAL EXPOSURE TO RADIATION: MAN

Part II. TYPE OF RADIATION

	Type of Radiation	QF[1]	Average Exposure Rate[2] mrad/wk	Approximate Flux to Give a Maximum Permissible Exposure in an 8-Hour Day[3]
	(A)	(B)	(C)	(D)
2	β rays and electrons	1	100	$\frac{4.3 \times 10^7}{(QF)P}$ electrons or β rays per sq cm per sec incident on tissue (≃23 electrons or 15 β per sq cm per sec of 1 Mev energy)
3	Thermal neutrons	2.5	40	700 thermal neutrons per sq cm per sec incident on tissue
4	Fast neutrons	10	10	19 neutrons of 2 Mev energy per sq cm per sec incident on tissue
5	α particles	10	10	$\frac{4.3 \times 10^7}{(QF)P}$ α particles per sq cm per sec incident on tissue (≃0.005 α particles of 5 Mev per sq cm per sec)
6	Protons	10	10	$\frac{4.3 \times 10^7}{(QF)P}$ protons per sq cm per sec incident on tissue (≃0.06 protons of 5 Mev per sq cm per sec)
7	Heavy ions	20	5	$\frac{4.3 \times 10^7}{(QF)P}$ heavy ions per sq cm per sec (≃0.0002 oxygen ions of 5 Mev per sq cm per sec)

/1/ Quality factor, a term used to express the modification of RBE due to LET (linear energy transfer of the radiation), *n* (relative damage factor), and other conditions. /2/ Permissible to eyes, gonads, and blood-forming organs (essentially total body exposure) of individuals 18 years or older. These values may be averaged over a year, provided the dose equivalent in any 13 weeks does not exceed 3 rem (rem = rad x QF). /3/ Rate based on a 20-mrem dose equivalent delivered to tissue in an 8-hour day (= 2.5 per QF mrad per hr). The rad in soft tissue is considered to correspond to an energy absorption of 100 ergs/g. The *P* is the stopping power in units of electron volts per g per sq cm of soft tissue. Mev = one million electron volts.

Contributor: Morgan, Karl Z.

Reference: National Research Council, Division of Physical Sciences. 1962. Nuclear instruments and their uses. J. Wiley, New York.

Part III. INTERNAL CONCENTRATION OF RADIONUCLIDES

Values are for radionuclides ingested (in water) or inhaled (in air). Any mixture of the radionuclides listed is considered permissible if the accumulated body burden in any organ, or the concentration in the contents of the gastrointestinal tract, does not reach a value that delivers a dose exceeding the maximum permissible dose-rate of 0.3 rem per week. **Type of Decay** (column C): α = alpha particle; β⁻ = negatron; β⁺ = positron; γ = gamma ray; e⁻ = internal conversion electron; ε = orbital electron capture; SF = spontaneous fission. **Radionuclide** (column D): s = soluble compounds of the radionuclide; i = insoluble compounds of the radionuclide. **Critical Organ** (columns F and I): GI = gastrointestinal tract; (S) = stomach; (SI) = small intestine; (ULI) = upper large intestine; (LLI) = lower large intestine. μc = microcurie, one millionth of a curie or 3.7×10^4 disintegrations per second.

	Radionuclide					Maximum Permissible Concentrations of Radionuclides					
						In Water			In Air		
	Z[1]	Symbol and Mass No.	Type of Decay	s or i	q[2]	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
1	1	H^3 (HTO or $H_2{}^3O$)	β⁻	s	1,000	Body tissue	0.1	0.03	Body tissue	5×10^{-6}	2×10^{-6}
2	4	Be^7	ε, γ	s	600[4]	GI (LLI)	0.05	0.02	Total body	6×10^{-6}	2×10^{-6}
3				i	....	GI (LLI)	0.05	0.02	Lung	10^{-6}	4×10^{-7}
4	6	C^{14} (CO_2)	β⁻	s	300	Fat	0.02	8×10^{-3}	Fat	4×10^{-6}	10^{-6}
5	9	F^{18}	β⁺	s	....	GI (SI)	0.02	8×10^{-3}	GI (SI)	5×10^{-6}	2×10^{-6}
6				i	....	GI (ULI)	0.01	5×10^{-3}	GI (ULI)	3×10^{-6}	9×10^{-7}
7	11	Na^{22}	β⁺, γ	s	10	Total body	10^{-3}	4×10^{-4}	Total body	2×10^{-7}	6×10^{-8}
8				i	....	GI (LLI)	9×10^{-4}	3×10^{-4}	Lung	9×10^{-9}	3×10^{-9}
9	11	Na^{24}	β⁻, γ	s	....	GI (SI)	6×10^{-3}	2×10^{-3}	GI (SI)	10^{-6}	4×10^{-7}
10				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	GI (LLI)	10^{-7}	5×10^{-8}

/1/ Z = atomic number. /2/ Maximum permissible burden in the total body resulting from maximum permissible concentration of the radionuclide in water or food when deposited in the critical organ (columns F and I). When other footnote numbers appear in column E, "q" pertains only to the critical organ specified in the footnote. /3/ That organ receiving the radiation dose that results in the greatest damage to the body. /4/ For total body.

continued

126. MAXIMUM PERMISSIBLE OCCUPATIONAL EXPOSURE TO RADIATION: MAN

Part III. INTERNAL CONCENTRATION OF RADIONUCLIDES

	Radionuclide					Maximum Permissible Concentrations of Radionuclides					
						In Water			In Air		
	Z[1]	Symbol and Mass No.	Type of Decay	s or i	q[2]	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
11	14	Si^{31}	β^-, γ	s	....	GI (S)	0.03	9×10^{-3}	GI (S)	6×10^{-6}	2×10^{-6}
12				i	....	GI (ULI)	6×10^{-3}	2×10^{-3}	GI (ULI)	10^{-6}	3×10^{-7}
13	15	P^{32}	β^-	s	6	Bone	5×10^{-4}	2×10^{-4}	Bone	7×10^{-8}	2×10^{-8}
14				i	....	GI (LLI)	7×10^{-4}	2×10^{-4}	Lung	8×10^{-8}	3×10^{-8}
15	16	S^{35}	β^-	s	90	Testis	2×10^{-3}	6×10^{-4}	Testis	3×10^{-7}	9×10^{-8}
16				i	....	GI (LLI)	8×10^{-3}	3×10^{-3}	Lung	3×10^{-7}	9×10^{-8}
17	17	Cl^{36}	β^-	s	80	Total body	2×10^{-3}	8×10^{-4}	Total body	4×10^{-7}	10^{-7}
18				i	....	GI (LLI)	2×10^{-3}	6×10^{-4}	Lung	2×10^{-8}	8×10^{-9}
19	17	Cl^{38}	β^-, γ	s	....	GI (S)	0.01	4×10^{-3}	GI (S)	3×10^{-6}	9×10^{-7}
20				i	....	GI (S)	0.01	4×10^{-3}	GI (S)	2×10^{-6}	7×10^{-7}
21	19	K^{42}	β^-, γ	s	....	GI (S)	9×10^{-3}	3×10^{-3}	GI (S)	2×10^{-6}	7×10^{-7}
22				i	....	GI (LLI)	6×10^{-4}	2×10^{-4}	GI (LLI)	10^{-7}	4×10^{-8}
23	20	Ca^{45}	β^-	s	30	Bone	3×10^{-4}	9×10^{-5}	Bone	3×10^{-8}	10^{-8}
24				i	....	GI (LLI)	5×10^{-3}	2×10^{-3}	Lung	10^{-7}	4×10^{-8}
25	20	Ca^{47}	β^-, γ	s	5	Bone	10^{-3}	5×10^{-4}	Bone	2×10^{-7}	6×10^{-8}
26				i	....	GI (LLI)	10^{-3}	3×10^{-4}	GI (LLI)	2×10^{-7}[5]	6×10^{-8}[5]
27	21	Sc^{46}	β^-, γ	s	10[6]	GI (LLI)	10^{-3}	4×10^{-4}	Liver	2×10^{-7}[7]	8×10^{-8}[7]
28				i	....	GI (LLI)	10^{-3}	4×10^{-4}	Lung	2×10^{-8}	8×10^{-9}
29	21	Sc^{47}	β^-, γ	s	....	GI (LLI)	3×10^{-3}	9×10^{-4}	GI (LLI)	6×10^{-7}	2×10^{-7}
30				i	....	GI (LLI)	3×10^{-3}	9×10^{-4}	GI (LLI)	5×10^{-7}	2×10^{-7}
31	21	Sc^{48}	β^-, γ	s	....	GI (LLI)	8×10^{-4}	3×10^{-4}	GI (LLI)	2×10^{-7}	6×10^{-8}
32				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	GI (LLI)	10^{-7}	5×10^{-8}
33	23	V^{48}	$\beta^+, \epsilon, \gamma$	s	....	GI (LLI)	9×10^{-4}	3×10^{-4}	GI (LLI)	2×10^{-7}	6×10^{-8}
34				i	......	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	6×10^{-8}	2×10^{-8}
35	24	Cr^{51}	ϵ, γ	s	800[illegible]	GI (LLI)	0.05	0.02	Total body	10^{-5}[7]	4×10^{-6}[7]
36				i	....	GI (LLI)	0.05	0.02	Lung	2×10^{-6}	8×10^{-7}
37	25	Mn^{52}	$\beta^+, \epsilon, \gamma$	s	....	GI (LLI)	10^{-3}	3×10^{-4}	GI (LLI)	2×10^{-7}	7×10^{-8}
38				i	....	GI (LLI)	9×10^{-4}	3×10^{-4}	Lung	10^{-7}	5×10^{-8}[7]
39	25	Mn^{54}	ϵ, γ	s	20[6]	GI (LLI)	4×10^{-3}	10^{-3}	Liver	4×10^{-7}	10^{-7}
40				i	....	GI (LLI)	3×10^{-3}	10^{-3}	Lung	4×10^{-8}	10^{-8}
41	25	Mn^{56}	β^-, γ	s	....	GI (LLI)	4×10^{-3}	10^{-3}	GI (LLI)	8×10^{-7}	3×10^{-7}
42				i	....	GI (LLI)	3×10^{-3}	10^{-3}	GI (LLI)	5×10^{-7}	2×10^{-7}
43	26	Fe^{55}	ϵ	s	1,000	Spleen	0.02	8×10^{-3}	Spleen	9×10^{-7}	3×10^{-7}
44				i	....	GI (LLI)	0.07	0.02	Lung	10^{-6}	3×10^{-7}
45	26	Fe^{59}	β^-, γ	s	20[8]	GI (LLI)	2×10^{-3}	6×10^{-4}	Spleen	10^{-7}	5×10^{-8}
46				i	....	GI (LLI)	2×10^{-3}	5×10^{-4}	Lung	5×10^{-8}	2×10^{-8}
47	27	Co^{57}	ϵ, γ, e^-	s	....	GI (LLI)	0.02	5×10^{-3}	GI (LLI)	3×10^{-6}	10^{-6}
48				i	....	GI (LLI)	0.01	4×10^{-3}	Lung	2×10^{-7}	6×10^{-8}
49	27	Co^{58m}	$\beta^+, \epsilon, \gamma$	s	....	GI (LLI)	0.08	0.03	GI (LLI)	2×10^{-5}	6×10^{-6}
50				i	....	GI (LLI)	0.06	0.02	Lung	9×10^{-6}	3×10^{-6}
51	27	Co^{58}	β^+, ϵ	s	....	GI (LLI)	4×10^{-3}	10^{-3}	GI (LLI)	8×10^{-7}	3×10^{-7}[9]
52				i	....	GI (LLI)	3×10^{-3}	9×10^{-4}	Lung	5×10^{-8}	2×10^{-8}
53	27	Co^{60}	β^-, γ	s	....	GI (LLI)	10^{-3}	5×10^{-4}	GI (LLI)	3×10^{-7}	10^{-7}[9]
54				i	....	GI (LLI)	10^{-3}	3×10^{-4}	Lung	9×10^{-9}	3×10^{-9}
55	28	Ni^{59}	ϵ	s	1,000	Bone	6×10^{-3}	2×10^{-3}	Bone	5×10^{-7}	2×10^{-7}
56				i	....	GI (LLI)	0.06	0.02	Lung	8×10^{-7}	3×10^{-7}
57	28	Ni^{63}	β^-	s	200	Bone	8×10^{-4}	3×10^{-4}	Bone	6×10^{-8}	2×10^{-8}
58				i	....	GI (LLI)	0.02	7×10^{-3}	Lung	3×10^{-7}	10^{-7}
59	28	Ni^{65}	β^-, γ	s	....	GI (ULI)	4×10^{-3}	10^{-3}	GI (ULI)	9×10^{-7}	3×10^{-7}
60				i	....	GI (ULI)	3×10^{-3}	10^{-3}	GI (ULI)	5×10^{-7}	2×10^{-7}
61	29	Cu^{64}	$\beta^-, \beta^+, \epsilon$	s	....	GI (LLI)	0.01	3×10^{-3}	GI (LLI)	2×10^{-6}	7×10^{-7}
62				i	....	GI (LLI)	6×10^{-3}	2×10^{-3}	GI (LLI)	10^{-6}	4×10^{-7}
63	30	Zn^{65}	$\beta^+, \epsilon, \gamma$	s	60	Total body	3×10^{-3}	10^{-3}[10,11]	Total body	10^{-7}[10,11]	4×10^{-8}[10]
64				i	....	GI (LLI)	5×10^{-3}	2×10^{-3}	Lung	6×10^{-8}	2×10^{-8}
65	30	Zn^{69m}	γ, e^-, β^-	s	0.7[12]	GI (LLI)	2×10^{-3}	7×10^{-4}	Prostate	4×10^{-7}	10^{-7}
66				i	....	GI (LLI)	2×10^{-3}	6×10^{-4}	GI (LLI)	3×10^{-7}	10^{-7}

/1/ Z = atomic number. /2/ Maximum permissible burden in the total body resulting from maximum permissible concentration of the radionuclide in water or food when deposited in the critical organ (columns F and I). When other footnote numbers appear in column E, "q" pertains only to the critical organ specified in the footnote. /3/ That organ receiving the radiation dose that results in the greatest damage to the body. /4/ For total body. /5/ Also lung. /6/ For liver. /7/ Also lower large intestine. /8/ For spleen. /9/ Also total body. /10/ Also prostate. /11/ Also liver. /12/ For prostate.

continued

126. MAXIMUM PERMISSIBLE OCCUPATIONAL EXPOSURE TO RADIATION: MAN

Part III. INTERNAL CONCENTRATION OF RADIONUCLIDES

	Radionuclide					Maximum Permissible Concentrations of Radionuclides					
						In Water			In Air		
	Z[1]	Symbol and Mass No.	Type of Decay	s or i	q[2]	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
67	30	Zn^{69}	β^-	s	0.8[12]	GI (S)	0.05	0.02	Prostate	7×10^{-6}	2×10^{-6}
68				i	....	GI (S)	0.05	0.02	GI (S)	9×10^{-6}	3×10^{-6}
69	31	Ga^{72}	β^-, γ	s	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	2×10^{-7}	8×10^{-8}
70				i	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	2×10^{-7}	6×10^{-8}
71	32	Ge^{71}	ϵ	s	....	GI (LLI)	0.05	0.02	GI (LLI)	10^{-5}	4×10^{-6}
72				i	....	GI (LLI)	0.05	0.02	Lung	6×10^{-6}	2×10^{-6}
73	33	As^{73}	ϵ, γ	s	300[4]	GI (LLI)	0.01	5×10^{-3}	Total body	2×10^{-6}	7×10^{-7}
74				i	....	GI (LLI)	0.01	5×10^{-3}	Lung	4×10^{-7}	10^{-7}
75	33	As^{74}	$\beta^-, \beta^+, \epsilon, \gamma$	s	....	GI (LLI)	2×10^{-3}	5×10^{-4}	GI (LLI)	3×10^{-7}	10^{-7}
76				i	....	GI (LLI)	2×10^{-3}	5×10^{-4}	Lung	10^{-7}	4×10^{-8}
77	33	As^{76}	β^-, γ	s	....	GI (LLI)	6×10^{-4}	2×10^{-4}	GI (LLI)	10^{-7}	4×10^{-8}
78				i	....	GI (LLI)	6×10^{-4}	2×10^{-4}	GI (LLI)	10^{-7}	3×10^{-8}
79	33	As^{77}	β^-, γ	s	....	GI (LLI)	2×10^{-3}	8×10^{-4}	GI (LLI)	5×10^{-7}	2×10^{-7}
80				i	....	GI (LLI)	2×10^{-3}	8×10^{-4}	GI (LLI)	4×10^{-7}	10^{-7}
81	34	Se^{75}	ϵ, γ	s	90	Kidney	9×10^{-3}	3×10^{-3}[9]	Kidney	10^{-6}[9]	4×10^{-7}
82				i	....	GI (LLI)	8×10^{-3}	3×10^{-3}	Lung	10^{-7}	4×10^{-8}
83	35	Br^{82}	β^-, γ	s	10	Total body	8×10^{-3}[13]	3×10^{-3}[13]	Total body	10^{-6}	4×10^{-7}
84				i	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	2×10^{-7}	6×10^{-8}
85	37	Rb^{86}	β^-, γ	s	30[9]	Pancreas	2×10^{-3}[9]	7×10^{-4}[9]	Pancreas	3×10^{-7}[9]	10^{-7}[9,11]
86				i	....	GI (LLI)	7×10^{-4}	2×10^{-4}	Lung	7×10^{-8}	2×10^{-8}
87	37	Rb^{87}	β^-	s	200[9,11]	Pancreas	3×10^{-3}	10^{-3}	Pancreas	5×10^{-7}	2×10^{-7}[9,11]
88				i	....	GI (LLI)	5×10^{-3}	2×10^{-3}	Lung	7×10^{-8}	2×10^{-8}
89	38	Sr^{85m}	ϵ, γ	s	....	GI (SI)	0.2	0.07	GI (SI)	4×10^{-5}	10^{-5}
90				i	....	GI (SI)	0.2	0.07	GI (SI)	3×10^{-5}	10^{-5}
91	38	Sr^{85}	ϵ, γ	s	60	Total body	3×10^{-3}	10^{-3}	Total body	2×10^{-7}	8×10^{-8}
92				i	....	GI (LLI)	5×10^{-3}	2×10^{-3}	Lung	10^{-7}	4×10^{-8}
93	38	Sr^{89}	β^-	s	4	Bone	3×10^{-4}	10^{-4}	Bone	3×10^{-8}	10^{-8}
94				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	4×10^{-8}	10^{-8}
95	38	Sr^{90}	β^-	s	2	Bone	10^{-5}	4×10^{-6}	Bone	10^{-9}	4×10^{-10}
96				i	....	GI (LLI)	10^{-3}	4×10^{-4}	Lung	5×10^{-9}	2×10^{-9}
97	38	Sr^{91}	β^-, γ	s	....	GI (LLI)	2×10^{-3}	7×10^{-4}	GI (LLI)	4×10^{-7}	2×10^{-7}
98				i	....	GI (LLI)	10^{-3}	5×10^{-4}	GI (LLI)	3×10^{-7}	9×10^{-8}
99	38	Sr^{92}	β^-, γ	s	....	GI (ULI)	2×10^{-3}	7×10^{-4}	GI (ULI)	4×10^{-7}	2×10^{-7}
100				i	....	GI (ULI)	2×10^{-3}	6×10^{-4}	GI (ULI)	3×10^{-7}	10^{-7}
101	39	Y^{90}	β^-	s	....	GI (LLI)	6×10^{-4}	2×10^{-4}	GI (LLI)	10^{-7}	4×10^{-8}
102				i	....	GI (LLI)	6×10^{-4}	2×10^{-4}	GI (LLI)	10^{-7}	3×10^{-8}
103	39	Y^{91m}	β^-, γ	s	....	GI (SI)	0.01	0.03	GI (SI)	2×10^{-5}	8×10^{-6}
104				i	....	GI (SI)	0.01	0.03	GI (SI)	2×10^{-5}	6×10^{-6}
105	39	Y^{91}	β^-, γ	s	5[14]	GI (LLI)	8×10^{-4}	3×10^{-4}	Bone	4×10^{-8}	10^{-8}
106				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	3×10^{-8}	10^{-8}
107	39	Y^{92}	β^-, γ	s	....	GI (ULI)	2×10^{-3}	6×10^{-4}	GI (ULI)	4×10^{-7}	10^{-7}
108				i	....	GI (ULI)	2×10^{-3}	6×10^{-4}	GI (ULI)	3×10^{-7}	10^{-7}
109	39	Y^{93}	β^-, γ, e^-	s	....	GI (LLI)	8×10^{-4}	3×10^{-4}	GI (LLI)	2×10^{-7}	6×10^{-8}
110				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	GI (LLI)	10^{-7}	5×10^{-8}
111	40	Zr^{93}	β^-, γ, e^-	s	100[14]	GI (LLI)	0.02	8×10^{-3}	Bone	10^{-7}	4×10^{-8}
112				i	....	GI (LLI)	0.02	8×10^{-3}	Lung	3×10^{-7}	10^{-7}
113	40	Zr^{95}	β^-, γ, e^-	s	20[4]	GI (LLI)	2×10^{-3}	6×10^{-4}	Total body	10^{-7}	4×10^{-8}
114				i	....	GI (LLI)	2×10^{-3}	6×10^{-4}	Lung	3×10^{-8}	10^{-8}
115	40	Zr^{97}	β^-, γ	s	....	GI (LLI)	5×10^{-4}	2×10^{-4}	GI (LLI)	10^{-7}	4×10^{-8}
116				i	....	GI (LLI)	5×10^{-4}	2×10^{-4}	GI (LLI)	9×10^{-8}	3×10^{-8}
117	41	Nb^{93m}	γ, e^-	s	200[14]	GI (LLI)	0.01	4×10^{-3}	Bone	10^{-7}	4×10^{-8}
118				i	....	GI (LLI)	0.01	4×10^{-3}	Lung	2×10^{-7}	5×10^{-8}
119	41	Nb^{95}	β^-, γ	s	40[4]	GI (LLI)	3×10^{-3}	10^{-3}	Total body	5×10^{-7}	2×10^{-7}[7]
120				i	....	GI (LLI)	3×10^{-3}	10^{-3}	Lung	10^{-7}	3×10^{-8}
121	41	Nb^{97}	β^-, γ	s	....	GI (ULI)	0.03	9×10^{-3}	GI (ULI)	6×10^{-6}	2×10^{-6}
122				i	....	GI (ULI)	0.03	9×10^{-3}	GI (ULI)	5×10^{-6}	2×10^{-6}

/1/ Z = atomic number. /2/ Maximum permissible burden in the total body resulting from maximum permissible concentration of the radionuclide in water or food when deposited in the critical organ (columns F and I). When other footnote numbers appear in column E, "q" pertains only to the critical organ specified in the footnote. /3/ That organ receiving the radiation dose that results in the greatest damage to the body. /4/ For total body. /7/ Also lower large intestine. /9/ Also total body. /11/ Also liver. /12/ For prostate. /13/ Also small intestine. /14/ For bone. /15/ For kidney.

continued

126. MAXIMUM PERMISSIBLE OCCUPATIONAL EXPOSURE TO RADIATION: MAN

Part III. INTERNAL CONCENTRATION OF RADIONUCLIDES

	Radionuclide					Maximum Permissible Concentrations of Radionuclides					
						In Water			In Air		
	Z[1]	Symbol and Mass No.	Type of Decay	s or i	q[2]	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
123	42	Mo^{99}	β^-, γ	s	8	Kidney	5×10^{-3}	2×10^{-3}	Kidney	7×10^{-7}	3×10^{-7}
124				i	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	2×10^{-7}	7×10^{-8}
125	43	Tc^{96m}	ϵ, γ, e^-	s	....	GI (LLI)	0.4	0.1	GI (LLI)	8×10^{-5}	3×10^{-5}
126				i	....	GI (LLI)	0.3	0.1	Lung	3×10^{-5}	10^{-5}
127	43	Tc^{96}	ϵ, γ	s	....	GI (LLI)	3×10^{-3}	10^{-3}	GI (LLI)	6×10^{-7}	2×10^{-7}
128				i	....	GI (LLI)	10^{-3}	5×10^{-4}	GI (LLI)	2×10^{-7}	8×10^{-8}
129	43	Tc^{97m}	ϵ, γ, e^-	s	....	GI (LLI)	0.01	4×10^{-3}	GI (LLI)	2×10^{-6}	8×10^{-7}
130				i	....	GI (LLI)	5×10^{-3}	2×10^{-3}	Lung	2×10^{-7}	5×10^{-8}
131	43	Tc^{97}	ϵ	s	60[16]	GI (LLI)	0.05	0.02	Kidney	10^{-5}[7]	4×10^{-6}[7]
132				i	....	GI (LLI)	0.02	8×10^{-3}	Lung	3×10^{-7}	10^{-7}
133	43	Tc^{99m}	β^-, γ	s	....	GI (ULI)	0.2	0.06	GI (ULI)	4×10^{-5}	10^{-5}
134				i	....	GI (ULI)	0.08	0.03	GI (ULI)	10^{-5}	5×10^{-6}
135	43	Tc^{99}	β^-	s	....	GI (LLI)	0.01	3×10^{-3}	GI (LLI)	2×10^{-6}	7×10^{-7}
136				i	....	GI (LLI)	5×10^{-3}	2×10^{-3}	Lung	6×10^{-8}	2×10^{-8}
137	44	Ru^{97}	ϵ, γ, e^-	s	....	GI (LLI)	0.01	4×10^{-3}	GI (LLI)	2×10^{-6}	8×10^{-7}
138				i	....	GI (LLI)	0.01	3×10^{-3}	GI (LLI)	2×10^{-6}[5]	6×10^{-7}
139	44	Ru^{103}	β^-, γ, e^-	s	....	GI (LLI)	2×10^{-3}	8×10^{-4}	GI (LLI)	5×10^{-7}	2×10^{-7}
140				i	....	....	....	....	Lung	8×10^{-8}	3×10^{-8}
141	44	Ru^{105}	β^-, γ, e^-	s	....	GI (ULI)	3×10^{-3}	10^{-3}	GI (ULI)	7×10^{-7}	2×10^{-7}
142				i	....	GI (ULI)	3×10^{-3}	10^{-3}	GI (ULI)	5×10^{-7}	2×10^{-7}
143	44	Ru^{106}	β^-, γ	s	....	GI (LLI)	4×10^{-4}	10^{-4}	GI (LLI)	8×10^{-8}	3×10^{-8}
144				i	....	GI (LLI)	3×10^{-4}	10^{-4}	Lung	6×10^{-9}	2×10^{-9}
145	45	Rh^{103m}	γ, e^-	s	....	GI (S)	0.4	0.1	GI (S)	8×10^{-5}	3×10^{-5}
146				i	....	GI (S)	0.3	0.1	GI (S)	6×10^{-5}	2×10^{-5}
147	45	Rh^{105}	β^-, γ	s	....	GI (LLI)	4×10^{-3}	10^{-3}	GI (LLI)	8×10^{-7}	3×10^{-7}
148				i	....	GI (LLI)	3×10^{-3}	10^{-3}	GI (LLI)	5×10^{-7}	2×10^{-7}
149	46	Pd^{103}	ϵ, γ, e^-	s	20[15]	GI (LLI)	0.01	3×10^{-3}	Kidney	10^{-6}	5×10^{-7}
150				i	....	GI (LLI)	8×10^{-3}	3×10^{-3}	Lung	7×10^{-7}	3×10^{-7}
151	46	Pd^{109}	β^-, γ, e^-	s	....	GI (LLI)	3×10^{-3}	9×10^{-4}	GI (LLI)	6×10^{-7}	2×10^{-7}
152				i	....	GI (LLI)	2×10^{-3}	7×10^{-4}	GI (LLI)	4×10^{-7}	10^{-7}
153	47	Ag^{105}	ϵ, γ	s	....	GI (LLI)	3×10^{-3}	10^{-3}	GI (LLI)	6×10^{-7}	2×10^{-7}
154				i	....	GI (LLI)	3×10^{-3}	10^{-3}	Lung	8×10^{-8}	3×10^{-8}
155	47	Ag^{110m}	β^-, γ	s	....	GI (LLI)	9×10^{-4}	3×10^{-4}	GI (LLI)	2×10^{-7}	7×10^{-8}
156				i	....	GI (LLI)	9×10^{-4}	3×10^{-4}	Lung	10^{-8}	3×10^{-9}
157	47	Ag^{111}	β^-, γ	s	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	3×10^{-7}	10^{-7}
158				i	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	2×10^{-7}	8×10^{-8}
159	48	Cd^{109}	ϵ, γ, e^-	s	20[6,15]	GI (LLI)	5×10^{-3}	2×10^{-3}	Liver	5×10^{-8}	2×10^{-8}[16]
160				i	....	GI (LLI)	5×10^{-3}	2×10^{-3}	Lung	7×10^{-8}	3×10^{-8}
161	48	Cd^{115m}	β^-, γ, e^-	s	3[6]	GI (LLI)	7×10^{-4}	3×10^{-4}	Liver	4×10^{-8}[15]	10^{-8}
162				i	....	GI (LLI)	7×10^{-4}	3×10^{-4}	Lung	4×10^{-8}	10^{-8}
163	48	Cd^{115}	β^-, γ, e^-	s	....	GI (LLI)	10^{-3}	3×10^{-4}	GI (LLI)	2×10^{-7}	8×10^{-8}
164				i	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	2×10^{-7}	6×10^{-8}
165	49	In^{113m}	γ, e^-	s	....	GI (ULI)	0.04	0.01	GI (ULI)	8×10^{-6}	3×10^{-6}
166				i	....	GI (ULI)	0.04	0.01	GI (ULI)	7×10^{-6}	2×10^{-6}
167	49	In^{114m}	$\beta^-, \epsilon, \gamma, e^-$	s	6[15]	GI (LLI)	5×10^{-4}	2×10^{-4}	Kidney	10^{-7}[7,17]	4×10^{-8}[7,17]
168				i	....	GI (LLI)	5×10^{-4}	2×10^{-4}	Lung	2×10^{-8}	7×10^{-9}
169	49	In^{115m}	β^-, γ, e^-	s	....	GI (ULI)	0.01	4×10^{-3}	GI (ULI)	2×10^{-6}	8×10^{-7}
170				i	....	GI (ULI)	0.01	4×10^{-3}	GI (ULI)	2×10^{-6}	6×10^{-7}
171	49	In^{115}	β^-	s	30[15]	GI (LLI)	3×10^{-3}	9×10^{-4}	Kidney	2×10^{-7}	9×10^{-8}
172				i	....	GI (LLI)	3×10^{-3}	9×10^{-4}	Lung	3×10^{-8}	10^{-8}
173	50	Sn^{113}	ϵ, γ, e^-	s	30[14]	GI (LLI)	2×10^{-3}	9×10^{-4}	Bone	4×10^{-7}	10^{-7}
174				i	....	GI (LLI)	2×10^{-3}	8×10^{-4}	Lung	5×10^{-8}	2×10^{-8}
175	50	Sn^{125}	$\beta^- \gamma, e^-$	s	....	GI (LLI)	5×10^{-4}	2×10^{-4}	GI (LLI)	10^{-7}	4×10^{-8}
176				i	....	GI (LLI)	5×10^{-4}	2×10^{-4}	Lung	8×10^{-8}	3×10^{-8}
177	51	Sb^{122}	β^-, γ	s	....	GI (LLI)	8×10^{-4}	3×10^{-4}	GI (LLI)	2×10^{-7}	6×10^{-8}
178				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	GI (LLI)	10^{-7}	5×10^{-8}
179	51	Sb^{124}	β^-, γ	s	....	GI (LLI)	7×10^{-4}	2×10^{-4}	GI (LLI)	2×10^{-7}[9]	5×10^{-8}
180				i	....	GI (LLI)	7×10^{-4}	2×10^{-4}	Lung	2×10^{-8}	7×10^{-9}

/1/ Z = atomic number. /2/ Maximum permissible burden in the total body resulting from maximum permissible concentration of the radionuclide in water or food when deposited in the critical organ (columns F and I). When other footnote numbers appear in column E, "q" pertains only to the critical organ specified in the footnote. /3/ That organ receiving the radiation dose that results in the greatest damage to the body. /5/ Also lung. /6/ For liver. /7/ Also lower large intestine. /9/ Also total body. /14/ For bone. /15/ For kidney. /16/ Also kidney. /17/ Also spleen.

continued

Part III. INTERNAL CONCENTRATION OF RADIONUCLIDES

	Radionuclide					Maximum Permissible Concentrations of Radionuclides					
						In Water			In Air		
	Z[1]	Symbol and Mass No.	Type of Decay	s or i	q[2]	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
181	51	Sb^{125}	β⁻, γ, e⁻	s	40[18]	GI (LLI)	3×10^{-3}	10^{-3}	Lung	5×10^{-7}	2×10^{-7}
182				i	....	GI (LLI)	3×10^{-3}	10^{-3}	Lung	3×10^{-8}	9×10^{-9}
183	52	Te^{125m}	γ, e⁻	s	20[20]	Kidney	5×10^{-3}[7]	2×10^{-3}[7,20]	Kidney	4×10^{-7}	10^{-7}
184				i	....	GI (LLI)	3×10^{-3}	10^{-3}	Lung	10^{-7}	4×10^{-8}
185	52	Te^{127m}	β⁻, γ, e⁻	s	7[20]	Kidney	2×10^{-3}[7,20]	6×10^{-4}	Kidney	10^{-7}[20]	5×10^{-8}[20]
186				i	....	GI (LLI)	2×10^{-3}	5×10^{-4}	Lung	4×10^{-8}	10^{-8}
187	52	Te^{127}	β⁻	s	....	GI (LLI)	8×10^{-3}	3×10^{-3}	GI (LLI)	2×10^{-6}	6×10^{-7}
188				i	....	GI (LLI)	5×10^{-3}	2×10^{-3}	GI (LLI)	9×10^{-7}	3×10^{-7}
189	52	Te^{129m}	β⁻, γ, e⁻	s	3[15,20]	GI (LLI)	10^{-3}[16,20]	3×10^{-4}	Kidney	8×10^{-8}	3×10^{-8}[20]
190				i	....	GI (LLI)	6×10^{-4}	2×10^{-4}	Lung	3×10^{-8}	10^{-8}
191	52	Te^{129}	β⁻, γ, e⁻	s	....	GI (S)	0.02	8×10^{-3}	GI (S)	5×10^{-6}	2×10^{-6}
192				i	....	GI (ULI)	0.02	8×10^{-3}	GI (ULI)	4×10^{-6}	10^{-6}
193	52	Te^{131m}	β⁻, γ, e⁻	s	....	GI (LLI)	2×10^{-3}	6×10^{-4}	GI (LLI)	4×10^{-7}	10^{-7}
194				i	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	2×10^{-7}	6×10^{-8}
195	52	Te^{132}	β⁻, γ, e⁻	s	....	GI (LLI)	9×10^{-4}	3×10^{-4}	GI (LLI)	2×10^{-7}	7×10^{-8}
196				i	....	GI (LLI)	6×10^{-4}	2×10^{-4}	GI (LLI)	10^{-7}	4×10^{-8}
197	53	I^{126}	β⁻, ε, γ	s	1	Thyroid	5×10^{-5}	2×10^{-5}	Thyroid	8×10^{-9}	3×10^{-9}
198				i	....	GI (LLI)	3×10^{-3}	9×10^{-4}	Lung	3×10^{-7}	10^{-7}
199	53	I^{129}	β⁻, γ, e⁻	s	3	Thyroid	10^{-5}	4×10^{-6}	Thyroid	2×10^{-9}	6×10^{-10}
200				i	....	GI (LLI)	6×10^{-3}	2×10^{-3}	Lung	7×10^{-8}	2×10^{-8}
201	53	I^{131}	β⁻, γ, e⁻	s	0.7	Thyroid	6×10^{-5}	2×10^{-5}	Thyroid	9×10^{-9}	3×10^{-9}
202				i	....	GI (LLI)	2×10^{-3}	6×10^{-4}	GI (LLI)	3×10^{-7}[5]	10^{-7}[5]
203	53	I^{132}	β⁻, γ, e⁻	s	0.3	Thyroid	2×10^{-3}	6×10^{-4}	Thyroid	2×10^{-7}	8×10^{-8}
204				i	....	GI (ULI)	5×10^{-3}	2×10^{-3}	GI (ULI)	9×10^{-7}	3×10^{-7}
205	53	I^{133}	β⁻, γ, e⁻	s	0.3	Thyroid	2×10^{-4}	7×10^{-5}	Thyroid	3×10^{-8}	10^{-8}
206				i	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	2×10^{-7}	7×10^{-8}
207	53	I^{134}	β⁻, γ	s	0.2	Thyroid	4×10^{-3}	10^{-3}	Thyroid	5×10^{-7}	2×10^{-7}
208				i	....	GI (S)	0.02	6×10^{-3}	GI (S)	3×10^{-6}	10^{-6}
209	53	I^{135}	β⁻, γ, e⁻	s	0.3	Thyroid	7×10^{-4}	2×10^{-4}	Thyroid	10^{-7}	4×10^{-8}
210				i	....	GI (LLI)	2×10^{-3}	7×10^{-4}	GI (LLI)	4×10^{-7}	10^{-7}
211	55	Cs^{131}	ε	s	700	Total body	0.07	0.02	Total body	10^{-5}[11]	4×10^{-6}[11]
212				i	....	GI (LLI)	0.03	9×10^{-3}	Lung	3×10^{-6}	10^{-6}
213	55	Cs^{134m}	β⁻, γ, e⁻	s	....	GI (S)	0.02	0.06	GI (S)	4×10^{-5}	10^{-5}
214				i	....	GI (ULI)	0.03	0.01	GI (ULI)	6×10^{-6}	2×10^{-6}
215	55	Gs^{134}	β⁻, γ	s	20	Total body	3×10^{-4}	9×10^{-5}	Total body	4×10^{-8}	10^{-8}
216				i	....	GI (LLI)	10^{-3}	4×10^{-4}	Lung	10^{-8}	4×10^{-9}
217	55	Gs^{135}	β⁻	s	200	Liver	3×10^{-3}	10^{-3}[9,17]	Liver	5×10^{-7}[17]	2×10^{-7}[9,17]
218				i	....	GI (LLI)	7×10^{-3}	2×10^{-3}	Lung	9×10^{-8}	3×10^{-8}
219	55	Gs^{136}	β⁻, γ	s	30	Total body	2×10^{-3}	9×10^{-4}	Total body	4×10^{-7}	10^{-7}
220				i	....	GI (LLI)	2×10^{-3}	6×10^{-4}	Lung	2×10^{-7}	6×10^{-8}
221	55	Gs^{137}	β⁻, γ, e⁻	s	30	Total body	4×10^{-4}	2×10^{-4}[21]	Total body	6×10^{-8}	2×10^{-8}
222				i	....	GI (LLI)	10^{-3}	4×10^{-4}	Lung	10^{-8}	5×10^{-9}
223	56	Ba^{131}	ε, γ	s	....	GI (LLI)	5×10^{-3}	2×10^{-3}	GI (LLI)	10^{-6}	4×10^{-7}
224				i	....	GI (LLI)	5×10^{-3}	2×10^{-3}	Lung	4×10^{-7}	10^{-7}
225	56	Ba^{140}	β⁻, γ	s	4[14]	GI (LLI)	8×10^{-4}	3×10^{-4}	Bone	10^{-7}	4×10^{-8}
226				i	....	GI (LLI)	7×10^{-4}	2×10^{-4}	Lung	4×10^{-8}	10^{-8}
227	57	La^{140}	β⁻, γ	s	....	GI (LLI)	7×10^{-4}	2×10^{-4}	GI (LLI)	2×10^{-7}	5×10^{-8}
228				i	....	GI (LLI)	7×10^{-4}	2×10^{-4}	GI (LLI)	10^{-7}	4×10^{-8}
229	58	Ge^{141}	β⁻, γ	s	30[6]	GI (LLI)	3×10^{-3}	9×10^{-4}	Liver	4×10^{-7}	2×10^{-7}[7,19]
230				i	....	GI (LLI)	3×10^{-3}	9×10^{-4}	Lung	2×10^{-7}	5×10^{-8}
231	58	Ge^{143}	β⁻, γ	s	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	3×10^{-7}	9×10^{-8}
232				i	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	2×10^{-7}	7×10^{-8}
233	58	Ge^{144}	α, β⁻, γ	s	5[14]	GI (LLI)	3×10^{-4}	10^{-4}	Bone	10^{-8}[11]	3×10^{-9}
234				i	....	GI (LLI)	3×10^{-4}	10^{-4}	Lung	6×10^{-9}	2×10^{-9}
235	59	Pr^{142}	β⁻, γ	s	....	GI (LLI)	9×10^{-4}	3×10^{-4}	GI (LLI)	2×10^{-7}	7×10^{-8}
236				i	....	GI (LLI)	9×10^{-4}	3×10^{-4}	GI (LLI)	2×10^{-7}	5×10^{-8}

/1/ Z = atomic number. /2/ Maximum permissible burden in the total body resulting from maximum permissible concentration of the radionuclide in water or food when deposited in the critical organ (columns F and I). When other footnote numbers appear in column E, "q" pertains only to the critical organ specified in the footnote. /3/ That organ receiving the radiation dose that results in the greatest damage to the body. /5/ Also lung. /6/ For liver. /7/ Also lower large intestine. /9/ Also total body. /11/ Also liver. /14/ For bone. /15/ For kidney. /16/ Also kidney. /17/ Also spleen. /18/ For lung. /19/ Also bone. /20/ Also testis. /21/ Also liver, spleen, and muscle.

continued

126. MAXIMUM PERMISSIBLE OCCUPATIONAL EXPOSURE TO RADIATION: MAN

Part III. INTERNAL CONCENTRATION OF RADIONUCLIDES

	Radionuclide					Maximum Permissible Concentrations of Radionuclides					
						In Water			In Air		
	Z[1]	Symbol and Mass No.	Type of Decay	s or i	q[2]	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
237	59	Pr^{143}	β^-	s	....	GI (LLI)	10^{-3}	5×10^{-4}	GI (LLI)	3×10^{-7}	10^{-7}
238				i	....	GI (LLI)	10^{-3}	5×10^{-4}	Lung	2×10^{-7}	6×10^{-8}
239	60	Nd^{144}	α	s	0.1	Bone	2×10^{-3}[7]	7×10^{-4}	Bone	8×10^{-11}	3×10^{-11}
240				i	....	GI (LLI)	2×10^{-3}	8×10^{-4}	Lung	3×10^{-10}	10^{-10}
241	60	Nd^{147}	α, β^-, γ	s	10[6]	GI (LLI)	2×10^{-3}	6×10^{-4}	Liver	4×10^{-7}[7]	10^{-7}[7]
242				i	....	GI (LLI)	2×10^{-3}	6×10^{-4}	Lung	2×10^{-7}	8×10^{-8}
243	60	Nd^{149}	β^-, γ	s	....	GI (LLI)	8×10^{-3}	3×10^{-3}	GI (LLI)	2×10^{-6}	6×10^{-7}
244				i	....	GI (ULI)	8×10^{-3}	3×10^{-3}	GI (ULI)	10^{-6}	5×10^{-7}
245	61	Pm^{147}	α, β^-	s	60[14]	GI (LLI)	6×10^{-3}	2×10^{-3}	Bone	6×10^{-8}	2×10^{-8}
246				i	....	GI (LLI)	6×10^{-3}	2×10^{-3}	Lung	10^{-7}	3×10^{-8}
247	61	Pm^{149}	β^-, γ	s	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	3×10^{-7}	10^{-7}
248				i	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	2×10^{-7}	8×10^{-8}
249	62	Sm^{147}	α	s	0.1	Bone	2×10^{-3}[7]	6×10^{-4}	Bone	7×10^{-11}	2×10^{-11}
250				i	....	GI (LLI)	2×10^{-3}	7×10^{-4}	Lung	3×10^{-10}	9×10^{-11}
251	62	Sm^{151}	β^-, γ	s	100[14]	GI (LLI)	0.01	4×10^{-3}	Bone	6×10^{-8}	2×10^{-8}
252				i	....	GI (LLI)	0.01	4×10^{-3}	Lung	10^{-7}	5×10^{-8}
253	62	Sm^{153}	β^-, γ	s	....	GI (LLI)	2×10^{-3}	8×10^{-4}	GI (LLI)	5×10^{-7}	2×10^{-7}
254				i	....	GI (LLI)	2×10^{-3}	8×10^{-4}	GI (LLI)	4×10^{-7}	10^{-7}
255	63	Eu^{152} (9.2 hr)	$\beta^-, \epsilon, \gamma$	s	....	GI (LLI)	2×10^{-3}	6×10^{-4}	GI (LLI)	4×10^{-7}	10^{-7}
256				i	....	GI (LLI)	2×10^{-3}	6×10^{-4}	GI (LLI)	3×10^{-7}	10^{-7}
257	63	Eu^{152} (13 yr)	$\beta^-, \epsilon, \gamma$	s	20[15]	GI (LLI)	2×10^{-3}	8×10^{-4}	Kidney	10^{-8}	4×10^{-9}
258				i	....	GI (LLI)	2×10^{-3}	8×10^{-4}	Lung	2×10^{-8}	6×10^{-9}
259	63	Eu^{154}	$\beta^-, \epsilon, \gamma$	s	5[15,19]	GI (LLI)	6×10^{-4}	2×10^{-4}	Kidney	4×10^{-9}[19]	10^{-9}[19]
260				i	....	GI (LLI)	6×10^{-4}	2×10^{-4}	Lung	7×10^{-9}	2×10^{-9}
261	63	Eu^{155}	β^-, γ	s	70[15]	GI (LLI)	6×10^{-3}	2×10^{-3}	Kidney	9×10^{-8}	3×10^{-8}[19]
262				i	....	GI (LLI)	6×10^{-3}	2×10^{-3}	Lung	7×10^{-8}	3×10^{-8}
263	64	Gd^{153}	ϵ, γ, e^-	s	90[14]	GI (LLI)	6×10^{-3}	2×10^{-3}	Bone	2×10^{-7}	8×10^{-8}
264				i	....	GI (LLI)	6×10^{-3}	2×10^{-3}	Lung	9×10^{-8}	3×10^{-8}
265	64	Gd^{159}	β^-, γ	s	....	GI (LLI)	2×10^{-3}	8×10^{-4}	GI (LLI)	5×10^{-7}	2×10^{-7}
266				i	....	GI (LLI)	2×10^{-3}	8×10^{-4}	GI (LLI)	4×10^{-7}	10^{-7}
267	65	Tb^{160}	β^-, γ	s	20[14]	GI (LLI)	10^{-3}	4×10^{-4}	Bone	10^{-7}[9,16]	3×10^{-8}
268				i	....	GI (LLI)	10^{-3}	4×10^{-4}	Lung	3×10^{-8}	10^{-8}
269	66	Dy^{165}	β^-, γ	s	....	GI (ULI)	0.01	4×10^{-3}	GI (ULI)	3×10^{-6}	9×10^{-7}
270				i	....	GI (ULI)	0.01	4×10^{-3}	GI (ULI)	2×10^{-6}	7×10^{-7}
271	66	Dy^{166}	β^-, γ, e^-	s	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	2×10^{-7}	8×10^{-8}
272				i	....	GI (LLI)	10^{-3}	4×10^{-4}	GI (LLI)	2×10^{-7}	7×10^{-8}
273	67	Ho^{166}	β^-, γ, e^-	s	....	GI (LLI)	9×10^{-4}	3×10^{-4}	GI (LLI)	2×10^{-7}	7×10^{-8}
274				i	....	GI (LLI)	9×10^{-4}	3×10^{-4}	GI (LLI)	2×10^{-7}	6×10^{-8}
275	68	Er^{169}	β^-, γ	s	....	GI (LLI)	3×10^{-3}	9×10^{-4}	GI (LLI)	6×10^{-7}	2×10^{-7}
276				i	....	GI (LLI)	3×10^{-3}	9×10^{-4}	Lung	4×10^{-7}	10^{-7}
277	68	Er^{171}	β^-, γ, e^-	s	....	GI (ULI)	3×10^{-3}	10^{-3}	GI (ULI)	7×10^{-7}	2×10^{-7}
278				i	....	GI (ULI)	3×10^{-3}	10^{-3}	GI (ULI)	6×10^{-7}	2×10^{-7}
279	69	Tm^{170}	$\beta^-, \epsilon, \gamma, e^-$	s	9[14]	GI (LLI)	10^{-3}	5×10^{-4}	Bone	4×10^{-8}	10^{-8}
280				i	....	GI (LLI)	10^{-3}	5×10^{-4}	Lung	3×10^{-8}	10^{-8}
281	69	Tm^{171}	β^-	s	90[14]	GI (LLI)	0.01	5×10^{-3}	Bone	10^{-7}	4×10^{-8}
282				i	....	GI (LLI)	0.01	5×10^{-3}	Lung	2×10^{-7}	8×10^{-8}
283	70	Yb^{175}	β^-, γ	s	....	GI (LLI)	3×10^{-3}	10^{-3}	GI (LLI)	7×10^{-7}	2×10^{-7}
284				i	....	GI (LLI)	3×10^{-3}	10^{-3}	GI (LLI)	6×10^{-7}	2×10^{-7}
285	71	Lu^{177}	β^-, γ	s	....	GI (LLI)	3×10^{-3}	10^{-3}	GI (LLI)	6×10^{-7}	2×10^{-7}
286				i	....	GI (LLI)	3×10^{-3}	10^{-3}	GI (LLI)	5×10^{-7}	2×10^{-7}
287	72	Hf^{181}	β^-, γ	s	4[8]	GI (LLI)	2×10^{-3}	7×10^{-4}	Spleen	4×10^{-8}	10^{-8}
288				i	....	GI (LLI)	2×10^{-3}	7×10^{-4}	Lung	7×10^{-8}	3×10^{-8}
289	73	Ta^{182}	β^-, γ	s	7[6]	GI (LLI)	10^{-3}	4×10^{-4}	Liver	4×10^{-8}	10^{-8}
290				i	....	GI (LLI)	10^{-3}	4×10^{-4}	Lung	2×10^{-8}	7×10^{-9}
291	74	W^{181}	ϵ, γ	s	....	GI (LLI)	0.01	4×10^{-3}	GI (LLI)	2×10^{-6}	8×10^{-7}
292				i	....	GI (LLI)	0.01	3×10^{-3}	Lung	10^{-7}	4×10^{-8}

/1/ Z = atomic number. /2/ Maximum permissible burden in the total body resulting from maximum permissible concentration of the radionuclide in water or food when deposited in the critical organ (columns F and I). When other footnote numbers appear in column E, "q" pertains only to the critical organ specified in the footnote. /3/ That organ receiving the radiation dose that results in the greatest damage to the body. /6/ For liver. /7/ Also lower large intestine. /8/ For spleen. /9/ Also total body. /14/ For bone. /15/ For kidney. /16/ Also kidney. /19/ Also bone.

continued

Part III. INTERNAL CONCENTRATION OF RADIONUCLIDES

	Radionuclide					Maximum Permissible Concentrations of Radionuclides					
						In Water			In Air		
	Z[1]	Symbol and Mass No.	Type of Decay	s or i	q[2]	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
293	74	W^{185}	β^-	s	....	GI (LLI)	4×10^{-3}	10^{-3}	GI (LLI)	8×10^{-7}	3×10^{-7}
294				i	....	GI (LLI)	3×10^{-3}	10^{-3}	Lung	10^{-7}	4×10^{-8}
295	74	W^{187}	β^-, γ	s	....	GI (LLI)	2×10^{-3}	7×10^{-4}	GI (LLI)	4×10^{-7}	2×10^{-7}
296				i	....	GI (LLI)	2×10^{-3}	6×10^{-4}	GI (LLI)	3×10^{-7}	10^{-7}
297	75	Re^{183}	ϵ, γ	s	80[4]	GI (LLI)	0.02[9]	6×10^{-3}	Total body	3×10^{-6}	9×10^{-7}
298				i	....	GI (LLI)	8×10^{-3}	3×10^{-3}	Lung	2×10^{-7}	5×10^{-8}
299	75	Re^{186}	β^-, γ	s	....	GI (LLI)	3×10^{-3}	9×10^{-4}	GI (LLI)	6×10^{-7}	2×10^{-7}
300				i	....	GI (LLI)	10^{-3}	5×10^{-4}	GI (LLI)	2×10^{-7}	8×10^{-8}
301	75	Re^{187}	β^-	s	300[22]	GI (LLI)	0.07	0.03[23]	Skin	9×10^{-6}	3×10^{-6}
302				i	....	GI (LLI)	0.04	0.02	Lung	5×10^{-7}	2×10^{-7}
303	75	Re^{188}	β^-, γ	s	....	GI (LLI)	2×10^{-3}	6×10^{-4}	GI (LLI)	4×10^{-7}	10^{-7}
304				i	....	GI (LLI)	9×10^{-4}	3×10^{-4}	GI (LLI)	2×10^{-7}	6×10^{-8}
305	76	Os^{185}	ϵ, γ, e^-	s	....	GI (LLI)	2×10^{-3}	7×10^{-4}	GI (LLI)	5×10^{-7}	2×10^{-7}
306				i	....	GI (LLI)	2×10^{-3}	7×10^{-4}	Lung	5×10^{-8}	2×10^{-8}
307	76	Os^{191m}	β^-, γ, e^-	s	....	GI (LLI)	0.07	0.03	GI (LLI)	2×10^{-5}	6×10^{-6}
308				i	....	GI (LLI)	0.07	0.02	Lung	9×10^{-6}	3×10^{-6}
309	76	Os^{191}	β^-, γ, e^-	s	....	GI (LLI)	5×10^{-3}	2×10^{-3}	GI (LLI)	10^{-6}	4×10^{-7}
310				i	....	GI (LLI)	5×10^{-3}	2×10^{-3}	Lung	4×10^{-7}	10^{-7}
311	76	Os^{193}	β^-	s	....	GI (LLI)	2×10^{-3}	6×10^{-4}	GI (LLI)	4×10^{-7}	10^{-7}
312				i	....	GI (LLI)	2×10^{-3}	5×10^{-4}	GI (LLI)	3×10^{-7}	9×10^{-8}
313	77	Ir^{190}	ϵ, γ	s	....	GI (LLI)	6×10^{-3}	2×10^{-3}	GI (LLI)	10^{-6}	4×10^{-7}
314				i	....	GI (LLI)	5×10^{-3}	2×10^{-3}	Lung	4×10^{-7}	10^{-7}
315	77	Ir^{192}	β^-, γ	s	6[15]	GI (LLI)	10^{-3}	4×10^{-4}	Kidney	10^{-7} [17]	4×10^{-8}
316				i	....	GI (LLI)	10^{-3}	4×10^{-4}	Lung	3×10^{-8}	9×10^{-9}
317	77	Ir^{194}	β^-	s	....	GI (LLI)	10^{-3}	3×10^{-4}	GI (LLI)	2×10^{-7}	8×10^{-8}
318				i	....	GI (LLI)	9×10^{-4}	3×10^{-4}	GI (LLI)	2×10^{-7}	5×10^{-8}
319	78	Pt^{191}	ϵ, γ	s	....	GI (LLI)	4×10^{-3}	10^{-3}	GI (LLI)	8×10^{-7}	3×10^{-7}
320				i	....	GI (LLI)	3×10^{-3}	10^{-3}	GI (LLI)	6×10^{-7}	2×10^{-7}
321	78	Pt^{193m}	ϵ, γ	s	....	GI (LLI)	0.03	0.01	GI (LLI)	7×10^{-6}	2×10^{-6}
322				i	....	GI (LLI)	0.03	0.01	GI (LLI)	5×10^{-6}	2×10^{-6}
323	78	Pt^{193}	ϵ	s	70	Kidney	0.03	9×10^{-3}	Kidney	10^{-6}	4×10^{-7}
324				i	....	GI (LLI)	0.05	0.02	Lung	3×10^{-7}	10^{-7}
325	78	Pt^{197m}	β^-, γ, e^-	s	....	GI (ULI)	0.03	0.01	GI (ULI)	6×10^{-6}	2×10^{-6}
326				i	....	GI (ULI)	0.03	9×10^{-3}	GI (ULI)	5×10^{-6}	2×10^{-6}
327	78	Pt^{197}	β^-, γ	s	....	GI (LLI)	4×10^{-3}	10^{-3}	GI (LLI)	8×10^{-7}	3×10^{-7}
328				i	....	GI (LLI)	3×10^{-3}	10^{-3}	GI (LLI)	6×10^{-7}	2×10^{-7}
329	79	Au^{196}	β^-, γ, e^-	s	....	GI (LLI)	5×10^{-3}	2×10^{-3}	GI (LLI)	10^{-6}	4×10^{-7}
330				i	....	GI (LLI)	4×10^{-3}	10^{-3}	Lung	6×10^{-7}	2×10^{-7}
331	79	Au^{198}	β^-, γ	s	....	GI (LLI)	2×10^{-3}	5×10^{-4}	GI (LLI)	3×10^{-7}	10^{-7}
332				i	....	GI (LLI)	10^{-3}	5×10^{-4}	GI (LLI)	2×10^{-7}	8×10^{-8}
333	79	Au^{199}	β^-, γ	s	....	GI (LLI)	5×10^{-3}	2×10^{-3}	GI (LLI)	10^{-6}	4×10^{-7}
334				i	....	GI (LLI)	4×10^{-3}	2×10^{-3}	GI (LLI)	8×10^{-7}	3×10^{-7}
335	80	Hg^{197m}	ϵ, γ, e^-	s	4	Kidney	6×10^{-3}	2×10^{-3}	Kidney	7×10^{-7}	3×10^{-7}
336				i	....	GI (LLI)	5×10^{-3}	2×10^{-3}	GI (LLI)	8×10^{-7}	3×10^{-7}
337	80	Hg^{197}	ϵ, γ, e^-	s	20	Kidney	9×10^{-3}	3×10^{-3}	Kidney	10^{-6}	4×10^{-7}
338				i	....	GI (LLI)	0.01	5×10^{-3}	GI (LLI)	3×10^{-6}	9×10^{-7}
339	80	Hg^{203}	β^-, γ, e^-	s	4	Kidney	5×10^{-4}	2×10^{-4}	Kidney	7×10^{-8}	2×10^{-8}
340				i	....	GI (LLI)	3×10^{-3}	10^{-3}	Lung	10^{-7}	4×10^{-8}
341	81	Tl^{200}	ϵ, γ	s	....	GI (LLI)	0.01	4×10^{-3}	GI (LLI)	3×10^{-6}	9×10^{-7}
342				i	....	GI (LLI)	7×10^{-3}	2×10^{-3}	GI (LLI)	10^{-6}	4×10^{-7}
343	81	Tl^{201}	ϵ, γ, e^-	s	....	GI (LLI)	9×10^{-3}	3×10^{-3}	GI (LLI)	2×10^{-6}	7×10^{-7}
344				i	....	GI (LLI)	5×10^{-3}	2×10^{-3}	GI (LLI)	9×10^{-7}	3×10^{-7}
345	81	Tl^{202}	ϵ, γ, e^-	s	....	GI (LLI)	4×10^{-3}	10^{-3}	GI (LLI)	8×10^{-7}	3×10^{-7}
346				i	....	GI (LLI)	2×10^{-3}	7×10^{-4}	Lung	2×10^{-7}	8×10^{-8}
347	81	Tl^{204}	β^-	s	10[15]	GI (LLI)	3×10^{-3}	10^{-3}	Kidney	6×10^{-7}	2×10^{-7} [7]
348				i	....	GI (LLI)	2×10^{-3}	6×10^{-4}	Lung	3×10^{-8}	9×10^{-9}

/1/ Z = atomic number. /2/ Maximum permissible burden in the total body resulting from maximum permissible concentration of the radionuclide in water or food when deposited in the critical organ (columns F and I). When other footnote numbers appear in column E, "q" pertains only to the critical organ specified in the footnote. /3/ That organ receiving the radiation dose that results in the greatest damage to the body. /4/ For total body. /7/ Also lower large intestine. /9/ Also total body. /15/ For kidney. /17/ Also spleen. /22/ For skin. /23/ Also skin.

continued

126. MAXIMUM PERMISSIBLE OCCUPATIONAL EXPOSURE TO RADIATION: MAN

Part III. INTERNAL CONCENTRATION OF RADIONUCLIDES

	Radionuclide					Maximum Permissible Concentrations of Radionuclides					
						In Water			In Air		
	Z[1]	Symbol and Mass No.	Type of Decay	s or i	q[2]	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
349	82	Pb^{203}	ε, γ	s	....	GI (LLI)	0.01	4×10^{-3}	GI (LLI)	3×10^{-6}	9×10^{-7}
350				i	....	GI (LLI)	0.01	4×10^{-3}	GI (LLI)	2×10^{-6}	6×10^{-7}
351	82	Pb^{210}	α, β⁻, γ	s	0.4	Kidney	4×10^{-6}[9]	10^{-6}[9]	Kidney	10^{-10}	4×10^{-11}
352				i	....	GI (LLI)	5×10^{-3}	2×10^{-3}	Lung	2×10^{-10}	8×10^{-11}
353	82	Pb^{212}	α, β⁻, γ, e⁻	s	0.02	Kidney	6×10^{-4}[7]	2×10^{-4}[7]	Kidney	2×10^{-8}	6×10^{-9}
354				i	....	GI (LLI)	5×10^{-4}	2×10^{-4}	Lung	2×10^{-8}	7×10^{-9}
355	83	Bi^{206}	ε, γ	s	1[15]	GI (LLI)	10^{-3}	4×10^{-4}	Kidney	2×10^{-7}[7]	6×10^{-8}
356				i	....	GI (LLI)	10^{-3}	4×10^{-4}	Lung	10^{-7}	5×10^{-8}
357	83	Bi^{207}	ε, γ	s	2[15]	GI (LLI)	2×10^{-3}	6×10^{-4}	Kidney	2×10^{-7}	6×10^{-8}
358				i	....	GI (LLI)	2×10^{-3}	6×10^{-4}	Lung	10^{-8}	5×10^{-9}
359	83	Bi^{210}	α, β⁻	s	0.04[15]	GI (LLI)	10^{-3}	4×10^{-4}	Kidney	6×10^{-9}	2×10^{-9}
360				i	....	GI (LLI)	10^{-3}	4×10^{-4}	Lung	6×10^{-9}	2×10^{-9}
361	83	Bi^{212}	α, β⁻, γ	s	0.01[16]	GI (S)	0.01	4×10^{-3}	Kidney	10^{-7}	3×10^{-8}
362				i	....	GI (S)	0.01	4×10^{-3}	Lung	2×10^{-7}	7×10^{-8}
363	84	Po^{210}	α	s	0.03	Spleen	2×10^{-5}[16]	7×10^{-6}	Spleen	5×10^{-10}[16]	2×10^{-10}[16]
364				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	2×10^{-10}	7×10^{-11}
365	85	At^{211}	α, ε, γ	s	0.02[24]	Thyroid	5×10^{-5}[24]	2×10^{-5}[24]	Thyroid	7×10^{-9}[24]	2×10^{-9}
366				i	....	GI (ULI)	2×10^{-3}	[illegible] $\times 10^{-4}$	Lung	3×10^{-8}	10^{-8}
367	86	Rn^{220}[25]	α, β⁻, γ, e⁻	...	....	....	....	....	Lung	3×10^{-7}	10^{-7}
368	86	Rn^{222}[25]	α, β⁻, γ	...	....	....	....	....	Lung	3×10^{-8}	10^{-8}
369	88	Ra^{223}	α, β⁻, γ	s	0.05	Bone	2×10^{-5}	7×10^{-6}	Bone	2×10^{-9}	6×10^{-10}
370				i	....	GI (LLI)	10^{-4}	4×10^{-5}	Lung	2×10^{-10}	8×10^{-11}
371	88	Ra^{224}	α, β⁻, γ, e⁻	s	0.06	Bone	7×10^{-5}	2×10^{-5}	Bone	5×10^{-9}	2×10^{-9}
372				i	....	GI (LLI)	2×10^{-4}	5×10^{-5}	Lung	7×10^{-10}	2×10^{-10}
373	88	Ra^{226}	α, β⁻, γ	s	0.1	Bone	4×10^{-7}	10^{-7}	Bone	3×10^{-11}	10^{-11}
374				i	....	GI (LLI)	9×10^{-4}	3×10^{-4}	GI (LLI)	2×10^{-7}	6×10^{-8}
375	88	Ra^{228}	α, β⁻, γ, e⁻	s	0.06	Bone	8×10^{-7}	3×10^{-7}	Bone	7×10^{-11}	2×10^{-11}
376				i	....	GI (LLI)	7×10^{-4}	3×10^{-4}	Lung	4×10^{-11}	10^{-11}
377	89	Ac^{227}	α, β⁻, γ	s	0.03	Bone	6×10^{-5}	2×10^{-5}	Bone	2×10^{-12}	8×10^{-13}
378				i	....	GI (LLI)	9×10^{-3}	3×10^{-3}	Lung	3×10^{-11}	9×10^{-12}
379	89	Ac^{228}	α, β⁻, γ, e⁻	s	0.05[6]	GI (ULI)	3×10^{-3}	9×10^{-4}	Liver	8×10^{-8}	3×10^{-8}[19]
380				i	....	GI (ULI)	3×10^{-3}	9×10^{-4}	Lung	2×10^{-8}	6×10^{-9}
381	90	Th^{227}	α, β⁻, γ	s	0.02[14]	GI (LLI)	5×10^{-4}	2×10^{-4}	Bone	3×10^{-10}	10^{-10}
382				i	....	GI (LLI)	5×10^{-4}	2×10^{-4}	Lung	2×10^{-10}	6×10^{-11}
383	90	Th^{228}	α, β⁻, γ, e⁻	s	0.02	Bone	2×10^{-4}	7×10^{-5}	Bone	9×10^{-12}	3×10^{-12}
384				i	....	GI (LLI)	4×10^{-4}	10^{-4}	Lung	6×10^{-12}	2×10^{-12}
385	90	Th^{230}	α, γ	s	0.05	Bone	5×10^{-5}	2×10^{-5}	Bone	2×10^{-12}	8×10^{-13}
386				i	....	GI (LLI)	9×10^{-4}	3×10^{-4}	GI (LLI)	10^{-11}	3×10^{-12}
387	90	Th^{231}	α, β⁻, γ	s	....	GI (LLI)	7×10^{-3}	2×10^{-3}	GI (LLI)	10^{-6}	5×10^{-7}
388				i	....	GI (LLI)	7×10^{-3}	2×10^{-3}	GI (LLI)	10^{-6}	4×10^{-7}
389	90	Th^{232}	α, β⁻, γ, e⁻	s	0.04	Bone	5×10^{-5}	2×10^{-5}	Bone	2×10^{-12}[26]	7×10^{-13}[26]
390				i	....	GI (LLI)	10^{-3}	4×10^{-4}	Lung	10^{-11}	4×10^{-12}
391	90	Th^{234}	β⁻, γ	s	4[14]	GI (LLI)	5×10^{-4}	2×10^{-4}	Bone	6×10^{-8}	2×10^{-8}
392				i	....	GI (LLI)	5×10^{-4}	2×10^{-4}	Lung	3×10^{-8}	10^{-8}
393	90	Th-nat	α, β⁻, γ, e⁻	s	0.01	Bone	3×10^{-5}	10^{-5}	Bone	2×10^{-12}[26]	6×10^{-13}[26]
394				i	....	GI (LLI)	3×10^{-4}	10^{-4}	Lung	4×10^{-12}	10^{-12}
395	91	Pa^{230}	α, β⁻, ε, γ	s	0.07[14]	GI (LLI)	7×10^{-3}	2×10^{-3}	Bone	2×10^{-9}	6×10^{-10}
396				i	....	GI (LLI)	7×10^{-3}	2×10^{-3}	Lung	8×10^{-10}	3×10^{-10}
397	91	Pa^{231}	α, β⁻, γ	s	0.02	Bone	3×10^{-5}	9×10^{-6}	Bone	10^{-12}	4×10^{-13}
398				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	10^{-10}	4×10^{-11}
399	91	Pa^{233}	β⁻, γ	s	40[15]	GI (LLI)	4×10^{-3}	10^{-3}	Kidney	6×10^{-7}	2×10^{-7}
400				i	....	GI (LLI)	3×10^{-3}	10^{-3}	Lung	2×10^{-7}	6×10^{-8}
401	92	U^{230}	α, β⁻, γ	s	0.01	Kidney	7×10^{-5}	2×10^{-5}	Kidney	3×10^{-10}	10^{-10}
402				i	....	GI (LLI)	10^{-4}	5×10^{-5}	Lung	10^{-10}	4×10^{-11}

/1/ Z = atomic number. /2/ Maximum permissible burden in the total body resulting from maximum permissible concentration of the radionuclide in water or food when deposited in the critical organ (columns F and I). When other footnote numbers appear in column E, "q" pertains only to the critical organ specified in the footnote. /3/ That organ receiving the radiation dose that results in the greatest damage to the body. /6/ For liver. /7/ Also lower large intestine. /9/ Also total body. /14/ For bone. /15/ For kidney. /16/ Also kidney. /19/ Also bone. /24/ Also ovary. /25/ The daughter elements of Rn^{220} and Rn^{222} are assumed present to the extent they occur in unfiltered air; for all other isotopes the daughter elements are not considered as part of the intake, and if present they must be considered on the basis of rules for mixtures. /26/ Provisional values.

continued

Part III. INTERNAL CONCENTRATION OF RADIONUCLIDES

	Radionuclide					Maximum Permissible Concentrations of Radionuclides					
						In Water			In Air		
	Z[1]	Symbol and Mass No.	Type of Decay	s or i	q[2]	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
403	92	U^{232}	α, β⁻, γ, e⁻	s	0.01	Bone	2×10^{-5}	8×10^{-6}	Bone	10^{-10}	3×10^{-11}
404				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	3×10^{-11}	9×10^{-12}
405	92	U^{233}	α, γ	s	0.05	Bone	10^{-4}	4×10^{-5}	Bone	5×10^{-10}	2×10^{-10}
406				i	....	GI (LLI)	9×10^{-4}	3×10^{-4}	Lung	10^{-10}	4×10^{-11}
407	92	U^{234}	α, γ	s	0.05	Bone	10^{-4}	4×10^{-5}	Bone	6×10^{-10}	2×10^{-10}
408				i	....	GI (LLI)	9×10^{-4}	3×10^{-4}	Lung	10^{-10}	4×10^{-11}
409	92	U^{235}	α, β⁻, γ	s	0.03	Kidney	10^{-4} [19]	4×10^{-5}	Kidney	5×10^{-10}	2×10^{-10} [19]
410				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	10^{-10}	4×10^{-11}
411	92	U^{236}	α, γ	s	0.06	Bone	10^{-4}	5×10^{-5}	Bone	6×10^{-10}	2×10^{-10}
412				i	....	GI (LLI)	10^{-3}	3×10^{-4}	Lung	10^{-10}	4×10^{-11}
413	92	U^{238}	α, γ, e⁻	s	0.005	Kidney	2×10^{-5}	6×10^{-6}	Kidney	7×10^{-11}	3×10^{-11}
414				i	....	GI (LLI)	10^{-3}	4×10^{-4}	Lung	10^{-10}	5×10^{-11}
415	92	U-nat	α, β⁻, γ, e⁻	s	0.005	Kidney	2×10^{-5}	6×10^{-6}	Kidney	7×10^{-11}	3×10^{-11}
416				i	....	GI (LLI)	5×10^{-4}	2×10^{-4}	Lung	6×10^{-11}	2×10^{-11}
417	92	U^{240} + Np^{240}	α, β⁻, γ, e⁻	s	....	GI (LLI)	10^{-3}	3×10^{-4}	GI (LLI)	2×10^{-7}	8×10^{-8}
418				i	....	GI (LLI)	10^{-3}	3×10^{-4}	GI (LLI)	2×10^{-7}	6×10^{-8}
419	93	Np^{237}	α, β⁻, γ	s	0.06	Bone	9×10^{-5}	3×10^{-5}	Bone	4×10^{-12}	10^{-12}
420				i	....	GI (LLI)	9×10^{-4}	3×10^{-4}	Lung	10^{-10}	4×10^{-11}
421	93	Np^{239}	α, β⁻, γ	s	....	GI (LLI)	4×10^{-3}	10^{-3}	GI (LLI)	8×10^{-7}	3×10^{-7}
422				i	....	GI (LLI)	4×10^{-3}	10^{-3}	GI (LLI)	7×10^{-7}	2×10^{-7}
423	94	Pu^{238}	α, γ	s	0.04	Bone	10^{-4}	5×10^{-5}	Bone	2×10^{-12}	7×10^{-13}
424				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	3×10^{-11}	10^{-11}
425	94	Pu^{239}	α, γ	s	0.04	Bone	10^{-4}	5×10^{-5}	Bone	2×10^{-12}	6×10^{-13}
426				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	4×10^{-11}	10^{-11}
427	94	Pu^{240}	α, γ	s	0.04	Bone	10^{-4}	5×10^{-5}	Bone	2×10^{-12}	6×10^{-13}
428				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	4×10^{-11}	10^{-11}
429	94	Pu^{241}	α, β⁻, γ	s	0.9	Bone	7×10^{-3}	2×10^{-3}	Bone	9×10^{-11}	3×10^{-11}
430				i	....	GI (LLI)	0.04	0.01	Lung	4×10^{-8}	10^{-8}
431	94	Pu^{242}	α	s	0.05	Bone	10^{-4}	5×10^{-5}	Bone	2×10^{-12}	6×10^{-13}
432				i	....	GI (LLI)	9×10^{-4}	3×10^{-4}	Lung	4×10^{-11}	10^{-11}
433	94	Pu^{243}	α, β⁻, γ, e⁻	s	....	GI (ULI)	0.01	3×10^{-3}	GI (ULI)	2×10^{-6}	6×10^{-7}
434				i	....	GI (ULI)	0.01	3×10^{-3}	GI (ULI)	2×10^{-6}	8×10^{-7}
435	94	Pu^{244}	α, β⁻, γ, e⁻ (99.7%)	s	0.04	Bone	10^{-4}	4×10^{-5}	Bone	2×10^{-12}	6×10^{-13}
436			SF (0.3%)	i	....	GI (LLI)	3×10^{-4}	10^{-4}	Lung	3×10^{-11}	10^{-11}
437	95	Am^{241}	α, γ	s	0.1	Kidney	10^{-4} [16]	4×10^{-5}	Kidney	6×10^{-12} [19]	2×10^{-12} [19]
438				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	10^{-10}	4×10^{-11}
439	95	Am^{242m}	α, β⁻, γ, ε, e⁻	s	0.07	Bone	10^{-4} [16]	4×10^{-5}	Bone	6×10^{-12} [16]	2×10^{-12} [19]
440				i	....	GI (LLI)	3×10^{-3}	9×10^{-4}	Lung	3×10^{-10}	9×10^{-11}
441	95	Am^{242}	α, β⁻, γ, ε, e⁻	s	0.06[6]	GI (LLI)	4×10^{-3}	10^{-3}	Liver	4×10^{-8}	10^{-8}
442				i	....	GI (LLI)	4×10^{-3}	10^{-3}	Lung	5×10^{-8}	2×10^{-8}
443	95	Am^{243}	α, β⁻, γ	s	0.05	Bone	10^{-4} [16]	4×10^{-5}	Bone	6×10^{-12} [16]	2×10^{-12} [16]
444				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	10^{-10}	4×10^{-11}
445	95	Am^{244}	α, β⁻, γ, e⁻	s	0.2[14,16]	GI (SI)	0.1	0.05	Bone	4×10^{-6} [16]	10^{-6} [16]
446				i	....	GI (SI)	0.1	0.05	GI (SI)	2×10^{-5} [5]	8×10^{-6} [5]
447	96	Cm^{242}	α, γ	s	0.05[6]	GI (LLI)	7×10^{-4}	2×10^{-4}	Liver	10^{-10}	4×10^{-11}
448				i	....	GI (LLI)	7×10^{-4}	2×10^{-4}	Lung	2×10^{-10}	6×10^{-11}
449	96	Cm^{243}	α, γ	s	0.09	Bone	10^{-4}	5×10^{-5}	Bone	6×10^{-12}	2×10^{-12}
450				i	....	GI (LLI)	7×10^{-4}	2×10^{-4}	Lung	10^{-10}	3×10^{-11}
451	96	Cm^{244}	α, γ	s	0.1	Bone	2×10^{-4}	7×10^{-5}	Bone	9×10^{-12}	3×10^{-12}
452				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	10^{-10}	3×10^{-11}
453	96	Cm^{245}	α, β⁻, γ	s	0.04	Bone	10^{-4}	4×10^{-5}	Bone	5×10^{-12}	2×10^{-12}
454				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	10^{-10}	4×10^{-11}
455	96	Cm^{246}	α	s	0.05	Bone	10^{-4}	4×10^{-5}	Bone	5×10^{-12}	2×10^{-12}
456				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	10^{-10}	4×10^{-11}
457	96	Cm^{247}	α, β⁻, γ, e⁻	s	0.04	Bone	10^{-4}	4×10^{-5}	Bone	5×10^{-12}	2×10^{-12}
458				i	....	GI (LLI)	6×10^{-4}	2×10^{-4}	Lung	10^{-10}	4×10^{-11}

/1/ Z = atomic number. /2/ Maximum permissible burden in the total body resulting from maximum permissible concentration of the radionuclide in water or food when deposited in the critical organ (columns F and I). When other footnote numbers appear in column E, "q" pertains only to the critical organ specified in the footnote. /3/ That organ receiving the radiation dose that results in the greatest damage to the body. /5/ Also lung. /6/ For liver. /14/ For bone. /16/ Also kidney. /19/ Also bone.

continued

126. MAXIMUM PERMISSIBLE OCCUPATIONAL EXPOSURE TO RADIATION: MAN

Part III. INTERNAL CONCENTRATION OF RADIONUCLIDES

	Radionuclide					Maximum Permissible Concentrations of Radionuclides					
						In Water			In Air		
	Z[1]	Symbol and Mass No.	Type of Decay	s or i	q[2]	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml	Critical Organ[3]	40-hr wk μc/ml	168-hr wk μc/ml
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)
459	96	Cm^{248}	α (89%)	s	0.005	Bone	10^{-5}	4×10^{-6}	Bone	6×10^{-13}	2×10^{-13}
460			SF (11%)	i	....	GI (LLI)	4×10^{-5}	10^{-5}	Lung	10^{-11}	4×10^{-12}
461	96	Cm^{249}	α, β⁻, γ, e⁻	s	1[14]	GI (S)	0.06	0.02	Bone	10^{-5}[27]	4×10^{-6}
462				i	....	GI (S)	0.06	0.02	GI (S)	10^{-5}	4×10^{-6}
463	97	Bk^{249}	α, β⁻, γ	s	0.7[14]	GI (LLI)	0.02	6×10^{-3}	Bone	9×10^{-10}	3×10^{-10}
464				i	....	GI (LLI)	0.02	6×10^{-3}	Lung	10^{-7}	4×10^{-8}
465	97	Bk^{250}	α, β⁻, γ, e⁻	s	0.05[14]	GI (ULI)	6×10^{-3}	2×10^{-3}	Bone	10^{-7}	5×10^{-8}
466				i	....	GI (ULI)	6×10^{-3}	2×10^{-3}	GI (ULI)	10^{-6}	4×10^{-7}
467	98	Cf^{249}	α, γ	s	0.04	Bone	10^{-4}	4×10^{-5}	Bone	2×10^{-12}	5×10^{-13}
468				i	....	GI (LLI)	7×10^{-4}	2×10^{-4}	Lung	10^{-10}	3×10^{-11}
469	98	Cf^{250}	α	s	0.04	Bone	4×10^{-4}	10^{-4}	Bone	5×10^{-12}	2×10^{-12}
470				i	....	GI (LLI)	7×10^{-4}	3×10^{-4}	Lung	10^{-10}	3×10^{-11}
471	98	Cf^{251}	α, γ	s	0.04	Bone	10^{-4}	4×10^{-5}	Bone	2×10^{-12}	6×10^{-13}
472				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	10^{-10}	3×10^{-11}
473	98	Cf^{252}	α, γ, SF	s	0.01[14]	GI (LLI)	2×10^{-4}	7×10^{-5}	Bone	6×10^{-12}	2×10^{-12}
474				i	....	GI (LLI)	2×10^{-4}	7×10^{-5}	Lung	3×10^{-11}	10^{-11}
475	98	Cf^{253}	α, β⁻, γ, e⁻	s	0.04[14]	GI (LLI)	4×10^{-3}	10^{-3}	Bone	8×10^{-10}	3×10^{-10}
476				i	....	GI (LLI)	4×10^{-3}	10^{-3}	Lung	8×10^{-10}	3×10^{-10}
477	98	Cf^{254}	SF	s	0.0007[14]	GI (LLI)	4×10^{-6}	10^{-6}	Bone	5×10^{-12}	2×10^{-12}
478				i	....	GI (LLI)	4×10^{-6}	10^{-6}	Lung	5×10^{-12}	2×10^{-12}
479	99	Es^{253}	α, β⁻, γ, e⁻	s	0.04[14]	GI (LLI)	7×10^{-4}	2×10^{-4}	Bone	8×10^{-10}	3×10^{-10}
480				i	....	GI (LLI)	7×10^{-4}	2×10^{-4}	Lung	6×10^{-10}	2×10^{-10}
481	99	Es^{254m}	α, β⁻, γ, e⁻	s	0.02[14]	GI (LLI)	5×10^{-4}	2×10^{-4}	Bone	5×10^{-9}	2×10^{-9}
482				i	....	GI (LLI)	5×10^{-4}	2×10^{-4}	Lung	6×10^{-9}	2×10^{-9}
483	99	Es^{254}	α, β⁻, γ, e⁻	s	0.02[14]	GI (LLI)	4×10^{-4}	10^{-4}	Bone	2×10^{-11}	6×10^{-12}
484				i	....	GI (LLI)	4×10^{-4}	10^{-4}	Lung	10^{-10}	4×10^{-11}
485	99	Es^{255}	α, β⁻, γ	s	0.04[14]	GI (LLI)	8×10^{-4}	3×10^{-4}	Bone	5×10^{-10}	2×10^{-10}
486				i	....	GI (LLI)	8×10^{-4}	3×10^{-4}	Lung	4×10^{-10}	10^{-10}
487	100	Fm^{254}	α, γ, e⁻ (99.9448%)	s	0.02[14]	GI (ULI)	4×10^{-3}	10^{-3}	Bone	6×10^{-8}	2×10^{-8}
488			SF (5.52×10^{-2}%)	i	....	GI (ULI)	4×10^{-3}	10^{-3}	Lung	7×10^{-8}	2×10^{-8}
489	100	Fm^{255}	α, γ	s	0.04[14]	GI (LLI)	10^{-3}	3×10^{-4}	Bone	2×10^{-8}	6×10^{-9}
490				i	....	GI (LLI)	10^{-3}	3×10^{-4}	Lung	10^{-8}	4×10^{-9}
491	100	Fm^{256}	SF	s	0.0008[14]	GI (ULI)	3×10^{-5}	9×10^{-6}	Bone	3×10^{-9}	10^{-9}
492				i	....	GI (ULI)	3×10^{-5}	9×10^{-6}	Lung	2×10^{-9}	6×10^{-10}

/1/ Z = atomic number. /2/ Maximum permissible burden in the total body resulting from maximum permissible concentration of the radionuclide in water or food when deposited in the critical organ (columns F and I). When other footnote numbers appear in column E, "q" pertains only to the critical organ specified in the footnote. /3/ That organ receiving the radiation dose that results in the greatest damage to the body. /14/ For bone. /27/ Also stomach.

Contributor: Morgan, Karl Z.

References: [1] International Commission on Radiological Protection. 1959. Radiation protection, II. Pergamon Press, New York. [2] International Commission on Radiological Protection. 1964. Radiation protection, IV. Pergamon Press, New York.

127. LATE EFFECTS OF IRRADIATION: MAMMALS

Radiation (columns A and B): c = curie, the quantity of radioactive nuclide in which the number of disintegrations is 3.7×10^{10}/sec; mc = millicurie, 1/1,000 of a curie or 3.7×10^{7} disintegrations/sec; μc = microcurie, one millionth of a curie or 3.7×10^{4} disintegrations/sec; ev = electron volt, the energy imparted to an electron when it is accelerated through a potential difference of one volt (1.602×10^{-12} ergs); Mev = one million electron volts, a unit of energy equal to 1.6×10^{-6} ergs; kv = kilovolt, a unit of electrical potential equal to 1,000 volts; n = neutron, a nuclear particle of zero charge and mass number 1; r = roentgen, the quantity of X- or γ-radiation such that the associated corpuscular emission per 0.001293 g of air produces, in air, ions carrying one electrostatic unit of electrical charge of either sign; rep = roentgen equivalent physical, the equivalent of 93 ergs/g energy absorption; rem = roentgen equivalent man (or mammal), the quantity of radiation absorbed in tissue, which gives the same observable effect as one rep of X or γ rays; rad = unit of absorbed dose (1 rad corresponds to 100 ergs/g of medium); RBE = relative biological effectiveness, i.e., ratio of absorbed dose, in rads, from reference X rays to the absorbed dose, in rads, from the given radiation field required to produce the same effect as the reference X rays (reference X rays in most cases have been those from 200-250 kv X-radiation or γ-radiation from Co^{60}). **Late Effects** (column D): figures separated by a slash (e.g., 13/16) give the number of individuals affected and number exposed. *Symbols:* > = greater than; ≧ = greater than or equal to; ≦ = less than or equal to.

	Radiation: Type	Radiation: Exposure	Latent Period	Late Effects	Reference
	(A)	(B)	(C)	(D)	(E)
	Man				
1	A-bomb	Epilation dose	2 yr	A-bomb cataract: Japan, 10 cases; USA, 1 case.	13,15
2	Hiroshima	Irradiated in utero, 1st half of pregnancy	5 yr	Microcephaly and mental retardation, 7/11 children within 1,200 m of hypocenter.	58
3	Japan	Area within 2,000 m of hypocenter	3-5 yr	Leukemia incidence 9.3 times that of nonexposed population of Hiroshima and Nagasaki (1948-1950, inclusive).	23
4		Area within 1,000 m of hypocenter	3-5 yr	Leukemia incidence 32 times that of nonexposed population (1948-1950, inclusive).	
5	Cyclotron	Epilation dose	2 yr	Cyclotron-induced cataract, 2 cases.	13,15
6	16 Mev neutrons, fast	400-500 n	2 mo-5 yr	Severe epidermolytic reaction, 13/16: skin atrophy and fibrosis, persistent ulcerations, diminished repair by normal tissues. Radiation osteitis. Severe bowel reactions.	69
7	0-20 Mev neutrons, fast (small γ components)	10-135 n	2-10 yr	Cataracts: severe, 3/10; slight to moderate, 4/10; minimal, 3/10. Chronic irradiation: no blood changes; mild epilation, 2 cases.	1
8	γ rays and fission neutrons	22.8-365 rads to total body	29 mo	Gross chromosome aberrations of leukocyte cultures, % abnormal cells: 22.8 rads, 4%; 339 rads, 28.2%; 365 rads, 18%. Minor aberrations of grossly normal cells: 22.8 rads, 83%; 339 rads, 53%; 365 rads, 67%.	4,5
9			42 mo	Gross chromosome aberrations of leukocyte cultures, % abnormal cells: 22.8 rads, 20%; 339 rads, 19%; 365 rads, 23%. Minor aberrations of grossly normal cells: 22.8 rads, 0%; 339 rads, 50%; 365 rads, 30%.	
10	Nuclear and allied radiations		6-8 yr	Peak incidence of leukemia.	49
11			After 10th yr	Diminishing incidence of leukemia; increasing incidence of other cancers.	
12	Radium (external)	1,000-1,500 mg-hr		Cessation of ovarian function, 77%/63.	57
13		1,500-2,000 mg-hr		Cessation of ovarian function, 6/7.	
	Radium[1]	Residual (ingested)			2,48, 75, 76
14		0.02-0.5 μg	14-48 yr	Radiation osteitis, 25%.	
15		0.5-2.0 μg	1-32 yr	Osteomyelitis of jaw and loss of teeth, 5/9; radiation osteitis, 8/9; pathological fractures, 3/9; giant cell tumor, 1/9; osteogenic sarcoma, 1/9; epidermoid carcinoma of nasopharynx, 1/9. High incidence of deafness and arthritis.	
16		2.7 μg	8-32 yr	Osteomyelitis of jaw and loss of teeth, 5/9; radiation osteitis, 8/9; pathological fracture, 1/9; fibrosarcoma, 1/9; epidermoid carcinoma of nasopharynx, 1/9.	
17		2-20 μg	6-8 yr	Radiation osteitis (osteosclerosis); osteogenic sarcoma deaths, 5/18; pathological fractures.	

/1/ Variable amounts of mesothorium also present in some instances.

continued

127. LATE EFFECTS OF IRRADIATION: MAMMALS

	Radiation		Latent Period	Late Effects	Reference
	Type	Exposure			
	(A)	(B)	(C)	(D)	(E)
			Man		
	Radium[1]	Residual (ingested)			
18		8-23 µg	7-21 yr	Osteomyelitis of jaw and loss of teeth, 6/8; radiation osteitis, 7/8; epidermoid carcinoma of nasopharynx, 1/8; osteogenic carcinoma, 1/8; pathological fractures, 3/8; leukemia, 1/8.	2,48, 75, 76
19		10-180 µg	1-8 yr	Anemia with hyperplastic marrow, jaw necrosis (13 cases).	
20		Residual, 1.0-10.0 µg (equivalent to 100-800 µg original dose)	20-30 yr posttreatment	24 cases: changes in bone density (similar to those in dead or dying bone) in patients having at least 1 µg; minimal changes with 0.5 µg; dental changes in all with at least 4 µg. Greatly enlarged haversian canals. Distortion of normal bone configuration, 7/24; edentia, mandibular lesions, 3/19; aseptic necrosis of bone, 7/24; fibrosarcoma, honeycombed teeth (pink tooth).	43
21	Uranium, radium ores	Variable doses	13-23 yr	Lung cancer in uranium miners of Joachimsthal and Schneeberg.	28,40
22	X ray	Variable doses	Months to years	Skin atrophy, telangiectasis, sclerosis, pigmentation, alopecia, altered vasomotion, diminished sweat and sebaceous function, loss of cutaneous ridges and fingerprints, ulcers and keratoses, malignancies, hyperkeratotic warty growths, deformed and brittle dry nails, loss of nails, fissures, subungual hyperkeratoses.	3,28, 51, 75, 76
23		Varied exposures (diagnostic radiology)		One leukemic death for every 46,000 X-ray examinations in Great Britain.	72
		Irradiation in utero		Incidence of leukemia and cancer per 10,000 children	45
24		No exposure		Leukemia--firstborn, 4.7; others, 3.6; all, 4.0. Cancer of CNS, 1.6; other cancers, 1.8.	
25		Exposed		Leukemia--firstborn, 6.9; others, 4.6; all, 6.1. Cancer of CNS, 2.5; other cancers, 2.5.	
26		1 or 2 films		Leukemia, 3.8; cancer of CNS, 2.7; other cancers, 2.7.	
27		Pelvimetry		Leukemia, 6.9; cancer of CNS, 2.3; other cancers, 2.1.	
28		100-300 r (200 & 1,000 kv)	60-680 da	Temporary drop in WBC count.	70
29			100-600 da	Temporary macrocytic anemia.	
30		500-624 r		94% castrated.	57
31		625 r to ovaries		Permanent cessation of menstruation, 72 patients.	
32		≤1,000 r to center of vertebrae	Followed 13 yr posttreatment	Vertebrae normal (irrespective of age), 45 children.	50,75, 76
33		1,000-2,000 r to spine	Followed 3-7 yr	"Transverse-line" growth disturbance of vertebrae (irrespective of age up to 6 yr), 45 children.	
34		Approximately 2,000 r to spine	Followed 2-13 yr	Contour irregularity of vertebrae, 44/45 children.	
35		1,500-8,500 r (therapeutic dose, eye tumor)	2 yr	Cataract, 7 cases.	13,15
36		3,500-5,000 r	8-28 mo	Lens opacities, 4 cases.	41
37		1,500-25,000 r (130-200 kv)	6-22 yr	Osteogenic sarcoma, 11 cases.	12
38		1,700-3,000 r (half-value layer 1.5 cu mm) to lower abdomen	6-18 mo	Nephrosclerosis, hypertension, elevated albuminuria, 22/55. Edema, anuria. Death from congestive heart failure and/or uremia, 7/55. Over 2,300 r, high risk of renal failure.	33
39	X ray, radium	4,000-6,700 r	5-20 yr	Sarcoma; osteogenic sarcoma. Therapy for lupus vulgaris, papillomata of bladder, actinomycosis, tubercular psoriasis.	30

/1/ Variable amounts of mesothorium also present in some instances.

continued

127. LATE EFFECTS OF IRRADIATION: MAMMALS

	Radiation		Latent Period	Late Effects	Reference
	Type	Exposure			
	(A)	(B)	(C)	(D)	(E)
	Man				
40	X-ray and radium equipment	Unknown		Leukemia in radiologists (4.68%), 9 times the incidence in nonradiological physicians (0.51%).	20,47, 74
	Dog				
41	Neutrons	0.012, 0.06, 0.11 n/da	1 yr	Reduction of lymphocytes only observed effect (dose given 6 da/wk).	7
42		1.7 n/da	1 yr	Mucoid conjunctivitis, keratoconjunctivitis and corneal opacities; reduced size of spleen and testes; increased incidence of infection; hypoplasia of bone marrow and regional lymph nodes; hemorrhage of lymph nodes, heart, stomach, small bowel and kidney; reduction of lymphocytes, neutrophils, and erythrocytes.	
43	Neutrons, fast	150 n	2 yr	Destruction and chronic inflammation of cornea, and changes in lens capsules and fibers, but no cataracts.	53
44		800-900 n	2 yr	Cataracts 60-75% of subjects.	
45	X ray	0.1 r/da (6 times/wk)	2 yr	Lowered sperm count, increase in abnormal sperm.	7
46		0.5 r/da	11 mo	Lowered sperm count, increase in abnormal sperm.	
47			2 yr	Partial testicular atrophy; slight reduction of lymphocytes.	
48		1.0 r/da	6 mo	Lymphopenia.	
49			9 mo	50% aspermic[a].	
50			1 yr	100% aspermic[a]; neutrophil reduction.	
51			2 yr	Severe injury of testes[a].	
52		3.0 r/da	2 mo	Lymphocyte and platelet reduction.	
53		6.0 r/da	9 mo	50% aspermic.	
54			1.5 yr	Severe injury of testes.	
55		10.0 r/da	2 mo	Lymphocyte, platelet, & erythrocyte depression.	
56			3.5 mo	50% aspermic.	
57			1.5 yr	Bone marrow hypoplasia; focal bowel and lymph node hemorrhages.	
58			6 mo	50% survival.	
	Guinea Pig				
59	Cobalt-60 (γ rays), external	15 r/da	106 da	50% survival.	73
60		30 r/da	63 da		
61		60 r/da	41 da		
62		90 r/da	20 da		
63		120 r/da	18 da		
64	Phosphorus-32	7,750 rep (external)	2 mo	Alopecia.	78
65	Radium, filtered (γ rays), repeated low dose	Nonradiated (controls)	38 mo	75% survival.	29,44, 70
66		0.11 r/da	38 mo	75% survival.	
67		1.1 r/da (1,050 r)	32 mo	50% survival.	
68		2.2 r/da (2,100 r)	32 mo	50% survival.	
69		4.4 r/da (2,400 r)	18 mo	50% survival; reduction of WBC.	
70		8.8 r/da (2,300 r)	5 mo	50% survival; recurrent anemia.	
	Mouse				
71	Carbon-14	100 μc sodium formate of C-14, intraperitoneally during gestation	Until postparturition	Normal litters; offspring show no differences from controls in weight, longevity, or tumor incidence. No lowered fertility.	68
72	Cesium-137 (γ rays)	258 r to total body before mating	Until parturition	Reduced size of litters: age at mating, 60-79 da--controls, 14.08; irradiated, 9.16; age at mating, 80-99 da--controls, 30.8; irradiated, 8.63; age at mating, 110-119 da--controls, 12.8; irradiated, 7.68; age at mating, 120-139 da--controls, 12.05; irradiated, 6.59.	26
73	Cobalt-60 (γ rays), external	90 r/da	52 da	50% survival.	73
74		115 r/da	37 da		
75		140 r/da	22 da		

/a/ If irradiation is stopped after one year, there is partial recovery of sperm four months later.

continued

127. LATE EFFECTS OF IRRADIATION: MAMMALS

	Radiation: Type (A)	Radiation: Exposure (B)	Latent Period (C)	Late Effects (D)	Reference (E)
	Mouse				
	Deuteron beams	Brain region			56
76		1-mm beam at 8,000 rads to cerebellum	2-7 mo	Significant variation in locomotor activity wheel tests & escape-avoidance conditioning.	
77		1-mm beam at 8,000 rads to both parietal regions	7 mo	Large lesions at end of Bragg zone owing to disappearance of nerve cell bodies, leaving fluid-filled cavities without structural detail.	
78	Neutrons, fast	2 rads/da, 2.24 neutron high, 0.287 neutron low; γ-irradiation--16 rads/da, 15.8 high, 2.26 low		Life shortening; RBE 10.	55
79	Neutrons, fast, or Cobalt-60 (γ rays)	3-50 rems daily		Life shortening; RBE independent of exposure time and may vary with dose rate.	52
80	Neutrons, fast (4 Mev); X ray (200 kv)	1 exposure		Cataractogenesis; RBE 4.	18,62, 63
81		3 exposures		Cataractogenesis; RBE 6.	
82	Neutrons, fast, 10^3 ev to ≥4 Mev, and γ rays (divided doses)	Nonradiated (controls)	51 wk	50% survival for controls and each dosage increment. For shortening life span, 1 n (divided small doses) is equivalent to 35 r. (For acute killing, 1 n is equivalent to 9 r.) Threshold for shortening life span is approximately 1 r/da and less than 0.1 n.	27
83		1 r/da	61 wk		
84		8.6 r/da	48 wk		
85		Nonradiated (controls)	70 wk		
86		0.115 n/da (total 32.2 n)	40 wk		
87		1.15 n/da (total 241.5 n)	30 wk		
88		4.3 n/da (total 301 n)	10 wk		
89		13 n/da (total 273 n)	3 wk		
90	Neutrons, fast, and X rays (single exposure)	Nonradiated (controls)	64 wk	50% survival for controls and each dosage increment. Terminal changes generalized. Atrophy. Increased incidence of mediastinal lymphomatosis.	27
91		500 [illegible]	58 wk		
92		700 [illegible]	39 wk		
93		26 n	52 wk		
94		50 n	48 wk		
95		78 n	42 wk		
96		90 n	6 wk		
97	Phosphorus-32	3,000-4,000 rep (external)	30 da	General epilation, skin atrophy, loss of ear tips, ulcerations, keratosis.	61,78
98			3-4 mo	Lens opacities (4,000 r).	
99			8 mo	Lens opacities (3,000 r).	
100			6-8 mo	Tumors; shortening of life span.	
101	Plutonium-239	3.1-15.6 μc/kg (iv)	190-250 da	Osteogenic sarcoma.	11,75, 76
102		>6.1 μc/kg (iv)		Marked shortening of life span.	
103	Radium-226	>12 μc/kg (iv)	250-300 da	Increased osteogenic sarcoma.	11,75, 76
104		>50 μc/kg (0.6-4,170 μc/kg, iv)		Marked shortening of life span: debilitation and increased incidence of infection.	
105	Radium, filtered (γ rays), repeated low dose	Nonradiated (controls)	24 mo	50% survival for controls and each dosage increment; increase in lymphatic leukemia, mammary and ovarian carcinoma.	44
106		1.1 r/da (760 r)	24 mo		
107		2.2 r/da (1,390 r)	22 mo		
108		4.4 r/da (2,640 r)	21 mo		
109		8.8 r/da (4,400 r)	17 mo		
	Strontium-89 (β rays)				10
110	Monthly injections	0.05 μc/g	500 da	Bone tumors begin to develop.	
111		0.1 μc/g	425 da		
112		0.2 μc/g	350 da		
113		0.5 μc/g	220 da		
114		1.0 μc/g	160 da		
115	Single injection	2.5 μc/g	200 da		
116		5.0 μc/g	150 da		
117	Uranium-232	0.1-1.0 μc/kg (iv)	575 da	Osteogenic sarcoma (probably significant); used 0.1-10.0 μc/kg.	11,75, 76
118		>1.0 μc/kg (iv)	575 da		
119	Uranium-233	2-5 μc/kg (iv)	575 da	Osteogenic sarcoma (probably significant); used 0.1-100 μc/kg.	11,75, 76
120		>5 μc/kg (iv)	575 da	Osteogenic sarcoma.	
121		>53 μc/kg (iv)	575 da	Shortening of life span.	
122	Uranium-238	>3.6 x 10^{-7} μc/kg (iv)	575 da	Possibly significant increase in osteogenic sarcoma.	11,75, 76

continued

127. LATE EFFECTS OF IRRADIATION: MAMMALS

	Radiation: Type	Radiation: Exposure	Latent Period	Late Effects	Reference
	(A)	(B)	(C)	(D)	(E)
	Mouse				
123	X ray	25-200 r to fetus early in pregnancy (equivalent to 2-6 wk, human)	Until birth	At birth, severe skeletal and other abnormalities, with clearly defined critical periods.	65
124		Irradiation of fetus late in pregnancy (equivalent to after 6 wk, human)	Until birth	Several weeks after birth: cataracts, hydrocephalus, behavior disturbances, skin lesions.	
125		400 r (single dose)	15-23 mo	Ovarian tumors 15 times that of controls.	25
126		600-1,000 r (divided doses)	9-14 mo	Myelosis 8 times that of controls.	
127			6-12 mo	Mediastinal lymphosarcoma 7 times that of controls.	
128	X ray (120 kv)	Nonradiated (controls)	526-570 da	Lymphomas, 3/36	31
129		600 r (150 r alternate weeks) to whole body	420-580 da	Lymphomas, 33/63.	
130		600 r (150 r alternate weeks) to whole body, mediastinum shielded	118-525 da	No lymphomas.	
131		1,200 r (300 r alternate weeks) to upper half of body	324-365 da	Lymphomas, 3/40.	
132		1,200 r (300 r alternate weeks) to alternate halves of body	420-508 da	Lymphomas, 3/37.	
133	X ray (250 kv)	50 r	17 wk	Lens opacities, 59% at 30 wk[3].	71
134		200 r	14 wk	Lens opacities, 100% at 22 wk[3].	
135		500 r	6 wk	Lens opacities, 100% at 17 wk[3].	
136		100 r to whole body	3 mo	Shortening of life span, 7%.	17
137		100-300 r to whole body	3 mo	Increase in thymic lymphoma.	
138		300 r to whole body	3 mo	Increase in myeloid leukemia; shortening of life span, 21%.	
139		300 r to head	3 mo	Ocular lens cataracts, 40%; shortening of life span, 2%.	
140		300 r to middle third of body	3 mo	Shortening of life span, 3%.	
141		300 r to lower third of body	3 mo	Increase of ovarian tumors; shortening of life span, 4%.	
142		260-520 r (1-4 exposures, males & females 164-730 da old)	Death	Life span shortened 4.6-26.2% for males, 8.8-36.5% for females.	32
143		550 r to whole body	5-6 mo	Decrease in fat of skin of female; permanent depression of DNA synthesis relative to RNA in kidneys of both sexes.	24
144		500 r, 550 r, 600 r (females 10 wk old)		Increased incidence of thymic lymphomas and ovarian tumors; greater severity of lens opacities than in controls.	16
145		750 r to whole body	6-10 mo	Weight reduction in body, heart, kidneys, and testes; increase in fat content of carcass.	22
	Rat				
146	Cerium-144	1-3 mc/kg	200 da	Osteogenic sarcoma, liver atrophy with ascites and jaundice.	42
147	Cobalt-60 (γ rays), external	20 r/da	332 da	50% survival; increased tumor frequency.	73
148		60 r/da	236 da		
149		70 r/da	72 da		
150		80 r/da	53 da		
151		90 r/da	48 da		
152		130 r/da	38 da		
153	Cobalt-60 (γ rays)	110 r (13-15th & 16-18th da of gestation)	Until parturition	Neonatal death rate higher.	54
154		150 r (14th & 20th da of gestation)			

/3/ The RBE of thermal neutrons calculated on the basis of the production of lens opacities was approximately nine time the RBE calculated on the basis of the production of lethality at 30 days.

continued

127. LATE EFFECTS OF IRRADIATION: MAMMALS

	Radiation: Type (A)	Radiation: Exposure (B)	Latent Period (C)	Late Effects (D)	Reference (E)
	Rat				
155	Cobalt-60 (γ rays)	220 r (12-16th & 17-20th da of gestation)	Until parturition	Neonatal death rate higher; average weaning weight lower in all irradiated groups; ovulation 20% in irradiated females; mature body and testes weight lower in irradiated males.	54
156	Neutrons	0.012-0.060 n/da	1 yr	No effects observed.	7
157		0.11 n/da	1 yr	Number of neoplasms 3 times that of controls (including leukemias).	
158		1.7 n/da	1 yr	Increased infection and incidence of neoplasms (high leukemia incidence); bilateral cataracts; hypoplasia of spleen; atrophy of testes and ovarian follicles; early reduction of lymphocytes; reduction of erythrocytes.	
159	Phosphorus-32	4,000-5,000 rep (external)	4-5 mo	Tumors, keratoses, lens opacities (low incidence), ulceration of scrotum and base of tail, alopecia.	78
160	Praseodymium-144	1-3 mc/kg	200 da	Osteogenic sarcoma, liver atrophy with ascites and jaundice.	42
161	Plutonium-239	0.02 μg/g (0.0031-0.0062 c/g)	300-400 da	Osteogenic sarcomas.	60
162		0.03 μc/g	3-7 mo	Areas of dead bone and calcified cartilage; resumption of normal bone growth at epiphysis; destruction of spermatogenic cells, atrophy of ovary.	8
163	Radium	0.125 μc/g	5 mo	Damage to epiphyseal cartilage, overgrowth with atypical bone, loss of normal bone cells; atrophy of ovary.	8,75, 76
164		0.5 μc/g	3-6 mo	Degenerative changes in ovary; damage to blood vessels.	
165		0.6 μc/g	5 mo	Damage to epiphyseal cartilage and marrow; production of abnormal bone.	
166	Strontium-89	0.05 μc/g	500 da	Osteogenic sarcomas.	60
167		0.1 μc/g	400 da		
168		0.5 μc/g (single injection)	400 da		
169		1.0 μc/g level (monthly injections)	250 da		
170		5.0 μc/g (single injection)	200 da		
	Strontium-90	10-30 da in drinking water			26
171		Total dose, 33 μc; skeletal burden, 1 μc (425 da old)	380 da	No leukemia; no osteogenic sarcoma.	
172		Total dose, 650 μc; skeletal burden, 2 μc (346 da old)	372 da	0.0007 leukemia/rat/wk; no osteogenic sarcoma.	
173		Total dose, 790 μc; skeletal burden, 11 μc (117 da old)	254 da	Moderate bone marrow damage; 0.0017 leukemia/rat/wk; 0.0076 osteogenic sarcoma/rat/wk.	
174		Total dose, 464 μc; skeletal burden, 33 μc (40 da old)	106 da	Atrophy of bone marrow cells; no leukemia; 0.023 osteogenic sarcoma/rat/wk.	
175	Thorium dioxide (α and γ rays)	0.3 ml	14 mo	Produced fibroblastic tumors, 14/60.	28
176		2.5 ml	10-17 mo	Produced sarcoma, 33/50.	
177		5.0 ml	10-17 mo	Produced sarcoma, 50/50.	
178	X ray	0.1 r/da (total 49 r)	81.7 wk	50% survival.	7
179		0.5 r/da (total 230 r)	76.7 wk	50% survival; increase in fibroadenoma of mammary gland.	
180		1.0 r/da (total 460 r)	76.9 wk	50% survival.	
181		10.0 r/da (total 3,500 r)	58.3 wk	50% survival; increase in leukemia.	
182		12.5-100.0 r (8th da of gestation)		Retardation of growth.	77
183		12.5-100.0 r (9th & 10th da of gestation)		Malformations, increased mortality, growth retardation.	
184		≥375 r to whole body		Enamel hypoplasia, retarded enamel dentin formation.	3,75, 76

continued

127. LATE EFFECTS OF IRRADIATION: MAMMALS

	Radiation: Type	Radiation: Exposure	Latent Period	Late Effects	Reference
	(A)	(B)	(C)	(D)	(E)
			Rat		
185	X ray	≧2,000 r (locally to teeth)		Retardation of eruption of incisors.	3,75, 76
186		4,000 r (locally to teeth)		Stoppage of growth of dentin (lengthwise) in incisors.	
187		500 r to whole body		5 months required for complete restoration of epithelium in testes (Vanderbilt's strain, adult males).	66
188	X ray (250 kv)	25-400 r to whole body (40 da old)	10.5-11 mo	Incidence of mammary gland neoplasia linear with doses between 25 and 400 r; above 400 r, incidence is either decreased or remains constant.	9
189		120-480 r to whole body (1-6 exposures, 3 mo old)	Death	Mean longevity: controls, 28.6 mo; 120 r, 24.9 mo; 240 r, 23.1 mo; 480 r, 20.2 mo.	39
190		400 r to whole body (either castrated or intact male, 40 da old)	16 mo[4]	50% incidence of breast neoplasms (more fibrosarcomas); total incidence lower than in irradiated females.	67
191		400 r (female 40 da old)	At end of 10 mo	79% tumor incidence, with one or more breast neoplasms.	19
192		773±88 r to abdomen only	420 da	50% mortality.	21
193		943±60 r to head only	168 da		
194		1,062±12 r to thorax only	90 da		
195		1,000 r (under 5% oxygen pressure) to whole body	Up to 500 da	Shortening of life span, nephrosclerosis, generalized arterioselerosis, hypertension, thrombocytopenia, anemia, increased susceptibility to oral hypertonic sodium chloride, earlier appearance of neoplasms.	6,34-38
196	Yttrium-91	2.0 μc/g	1-3 mo	Damage to epiphyseal cartilage, production of atypical bone; increase in spleen hematopoiesis.	8
197		20-30 mc/kg (1 dose orally), or 1-2 mc/kg/da, 6 da/wk for 3 mo	200-400 da	A variety of intestinal lesions with obstruction. Yttrium essentially not absorbed from intestinal tract.	42
			Rabbit		
198	Neutrons	0.012-0.11 n/da, 6 doses/wk	1 yr	No observed effects.	7
199		1.7 n/da	1 yr	Increased incidence of infection; hypoplasia of bone marrow; atrophy of testes; reduction of lymphocytes; neutrophils depressed after 8 wk, erythrocytes after 32-35 wk.	
200		3.7 n/wk (52.7-83.7 n, total)	4-12 mo	No lens changes.	53
201		33-100 n (single doses)	2-5 mo	Cataracts of posterior lens.	
202	Fission	3×10^{10} particles/ml	125 da	Cataracts (2×10^{9} particles/ml, or less, is threshold for lens opacities).	14
203	14 Mev	8×10^{10} particles/ml	125 da		
204	Phosphorus-32 (external)	2,500-3,000 rep	2 mo	Graying of fur.	78
205		5,000 rep		Epilation; recovery by 10 wk.	
206		7,500 rep		Permanent epilation, ulcerations.	
207		15,000 rep		Emaciation.	
208	Radium	100 μg in 90 da ($RaSO_4$ in glycerine, orally)	2 mo	Mottling and shortening of incisors.	28,64
209			5-18 mo	Pathological fractures, alopecia.	
210			9 mo	Jaw abscesses; rarefaction of mandible and other bones (generalized osteoporosis and necrosis); weight loss; mild, progressive, regenerative anemia, with hyperplasia and fibrosis of marrow, lymph nodes, spleen.	
211	Strontium-90	100 μc/kg (iv)	90 da	% of controls: total body wt, 92%; wt of femur, 81%; wt of tibia, 91%; length of tibia, 98%.	46
212		600 μc/kg (iv)	90 da	% of controls: total body wt, 34%; wt of femur, 71%; wt of tibia, 70%; length of tibia, 69%.	
213	Thorium dioxide (α and γ rays)	Intravenous injection		Osteosarcoma; hematopoietic depression and damage to liver and spleen. Deposited in reticuloendothelial system.	59

/4/ Longer interval than for irradiated females.

continued

	Radiation Type	Radiation Exposure	Latent Period	Late Effects	Reference
	(A)	(B)	(C)	(D)	(E)
			Rabbit		
214	X ray	0.1-0.5 r/da	1 yr	No changes detected.	7
215		1.0 r/da	1 yr	Possible testicular injury.	
216		10 r/da	8 wk	Lymphocytes significantly decreased.	
217			3 mo	Platelets decreased.	
218			1 yr	Erythrocytes decreased; testicular injury; ovarian follicles disappear.	
219		≤250 r (1.2 Mev)	150 da	Threshold for production of lens opacities.	14
220		500 r	125 da	Cataracts.	

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XII. PARASITISM

128. ARTHROPOD PARASITES: MAMMALS AND BIRDS

Many of the arthropods listed are known to be parasites of man. Some of these are identified by an asterisk (*).

	Species (Common Name); Distribution	Free Stage Location	Host [Location and Stage in Host]	Effect on Host	Reference
	(A)	(B)	(C)	(D)	(E)
	Pentastomida				
1	*Linguatula serrata* (tongue worm); worldwide	Eggs swallowed, hatched in alimentary tract of herbivores; larvae, nymphs develop in mesenteries	Mammals, birds. [Eggs expelled in respiratory tract; adults in nasal passages]	Severe irritation and blockage of nasal passages.	11
	Arachnida				
2	*Amblyomma americanum** (lone-star tick); N., Cen., & S. America	Eggs in soil; unfed larvae, nymphs, adults on grass	Cattle, dog, horse, goat, sheep, occasionally birds. [External--on host only while feeding]	Damage to hide, milk reduction. Vector of organisms causing Rocky Mt. spotted fever, Q fever. Larvae, nymphs, adults are bloodsuckers.	1,13
3	*Argas persicus* (fowl tick); warm & temperate semi-arid regions of world	All stages in crevices, cracks of housing, under bark of trees	Domestic fowl, occasionally wild birds. [External--on host only while feeding]	Anemia, leg weakness, egg reduction, occasionally death. Vector of organisms causing fowl spirochetosis, spiroplasmosis. Nymphs, adults are bloodsuckers.	1,3,13
4	*Bdellonyssus sylviarum* (northern fowl mite); United States, Canada, Mexico, Europe, S. Africa	Eggs on feathers, in nests; other stages on surroundings	Poultry, wild birds. [External; on body and feathers]	Skin lesions, egg reduction, retarded growth, anemia. Harborer of neurotropic viruses. Larvae, nymphs, adults are bloodsuckers.	1,3
5	*Boophilus annulatus** (cattle tick); N. America	Eggs on soil; unfed larvae on grass	Principally ungulates. [External]	Damage to hide, milk reduction. Vector of organisms causing Texas cattle fever. Larvae, nymphs, adults are bloodsuckers.	1,2, 11, 13
6	*Demodex canis* (dog follicle mite); worldwide	None	Dog. [Eggs, nymphs, adults in hair follicles and sebaceous glands]	Follicle inflammation, mange, thickened skin, alopecia, emaciation; sometimes death.	1,11
7	*Dermacentor andersoni** (Rocky Mountain wood tick); Western N. America	Eggs on soil	Most mammals. [External; larvae, nymphs on most small animals; adults usually on larger animals during feeding period]	Paralysis, particularly in sheep. Vector of organisms causing Rocky Mt. spotted fever, tularemia, equine encephalomyelitis, anaplasmosis. Larvae, nymphs, adults are bloodsuckers.	11,13
8	*D. variabilis* (American dog tick); N. America	Eggs on soil; unfed larvae, nymphs, adults on vegetation until host is found	Principally dog; other domestic and wild animals. [External--on host only while feeding; larvae, nymphs mainly attack rodents and other small animals]	Skin damage. Vector of organisms causing bovine anaplasmosis, tularemia, Rocky Mt. spotted fever. Larvae, nymphs, adults are bloodsuckers.	1,13
9	*Dermanyssus gallinae* (chicken mite); worldwide	Eggs, non-feeding larvae, nymphs, adults in crevices of coops, roosts	Poultry, other birds. [External]	Decreased egg production, retarded growth, anemia; sometimes death. Vector of organisms causing spirochetosis, fowl cholera. Larvae, nymphs, adults are bloodsuckers; nocturnal feeders only.	1,3
10	*Eutrombicula alfreddugesi* (chigger); N. & S. America, W. Indies	Active forms in grasses, shrubs, brambles	Domestic and wild vertebrates. [External]	Irritation due to toxins; sometimes death (small poultry). Larvae are bloodsuckers.	1,11, 13

continued

128. ARTHROPOD PARASITES: MAMMALS AND BIRDS

	Species (Common Name); Distribution	Free Stage Location	Host [Location and Stage in Host]	Effect on Host	Reference
	(A)	(B)	(C)	(D)	(E)
			Arachnida		
11	*Ixodes ricinus scapularis* (black-legged tick); principally Europe	Eggs on soil; larvae, nymphs, adults on grass and shrubbery until host is found	Principally dog; other domestic and wild animals. [External--on host only while feeding; adults on head, neck of dog; on flank, leg, under tail of other animals]	Anemia. Vector of cattle redwater fever, louping ill virus, tick-borne fever virus of sheep. Larvae, nymphs are bloodsuckers in ear, eyelid, head, rarely body.	1,11
12	*Knemidokoptes mutans* (scaly-leg mite); worldwide	None	Chicken, turkey, other domestic birds. [External; all active stages in tunnels between scales, feet, legs, neck, comb]	Inflammation, keratinization between scales of feet, legs; lameness.	1,3,11
13	*Otobius megnini** (ear tick); United States, Mexico, S. America, S. Africa	Eggs on ground, in cracks; adults, unattached larvae in outbuildings	Domestic animals. [Inside ears]	Ear inflammation, anorexia, dullness; sometimes death. Larvae, nymphs are bloodsuckers.	1,11, 13
14	*Otodectes cyanotis* (ear mite); worldwide	None	Dog, cat, ferret. [All stages in ears; sometimes external]	Inflammation, ear scabs, headshaking, scratching, droopy ears with discharge; epileptiform fits (severe cases).	1,11
15	*Psoroptes equi ovis*[1] (sheep-scab mite); worldwide	None	Sheep. [External; all active stages on skin around edge of lesions]	Scabbing; wool loss from biting, scratching; emaciation; sometimes death.	1,11, 13
16	*Rhipicephalus sanguineus** (brown dog tick); worldwide	Active forms near habitat of dog	Principally dog. [External]	Vector of organisms causing canine piroplasmosis, cattle gall sickness. Larvae, nymphs, adults are bloodsuckers.	1,11
17	*Sarcoptes scabiei** (itch mite); worldwide	None	Most mammals, sheep (on head). [External; all active stages in skin tunnels]	Scratching, papules, vesicles, keratinization, alopecia, mange, emaciation; sometimes death.	1,11, 13
			Insecta		
18	*Aedes dorsalis** (mosquito); N. America, Europe, northern Africa	Immature forms in moist soil; eggs survive long periods of drying in soil	Warm-blooded animals. [External]	Adult females are bloodsuckers. Vectors of organisms causing equine encephalomyelitis.	9,11
19	*Anopheles punctipennis** (mosquito); N. America	Immature forms in streams, ponds of hilly country	Warm-blooded animals. [External; where hair or feathers are thinnest]	Adult females are bloodsuckers. Vectors of organisms causing dog heartworm.	9
20	*Bovicola bovis* (cattle-biting louse); N. & S. America, Europe, Africa, Australia	None	Cattle. [External; eggs on hair; nymphs, adults feed on skin]	Reduced vigor, irritation, scaly skin.	11,13
21	*Cimex lectularius** (bedbug); worldwide	All stages in cracks, crevices, similar hiding places	Domestic animals, poultry. [External]	Skin irritation, welts. Nymphs, adults are bloodsuckers.	11,13
22	*Chrysops discalis* (deerfly); Western N. America	Eggs near water, larvae in water, pupae in mud	Principally horse, cattle. [External; mainly on underside of abdomen, neck, withers]	Vector of tularemia, surra. Adults are bloodsuckers.	5,11
23	*Cochliomyia hominivorax**[2] (screwworm); tropical & subtropical areas of western hemisphere	Pupae in soil, adults in pastures	Obligatory parasite of warm-blooded animals, including livestock, wild mammals, dog, cat. [Eggs deposited on edges of wounds]	Infection and extension of wounds; untreated host invariably dies.	4,8,10

/1/ Other varieties infest various domestic animals. /2/ Adult stage of *C. macellaria* (secondary screwworm) resembles *C. hominivorax* in appearance, but differs by being a secondary invader (facultative parasite), and by breeding in carcasses. Larvae occasionally infest wool or necrotic wounds.

continued

128. ARTHROPOD PARASITES: MAMMALS AND BIRDS

	Species (Common Name); Distribution	Free Stage Location	Host [Location and Stage in Host]	Effect on Host	Reference
	(A)	(B)	(C)	(D)	(E)
	Insecta				
24	*Ctenocephalides canis* (dog flea); worldwide	Immature forms associated with nest or sleeping area of host; adults on ground part of time	Cat, dog, swine, other animals. [External]	Coat damaged from biting, scratching. *C. canis* and *C. felis* are vectors of dog and dwarf tapeworms, heartworm, plague, epidemic typhus. Adults are bloodsuckers.	6,11, 17
25	*C. felis** (cat flea); worldwide				
26	*Cuclotogaster heterographus* (chicken head louse); worldwide	None	Chicken, partridge. [External; nymphs, adults on skin and feathers of head, neck; eggs on feathers]	Irritation.	3,11
27	*Culex quinquefasciatus** (southern house mosquito); worldwide from 60°N to 50°S latitude	Immature forms in stagnant water, ponds, ditches	Warm-blooded animals, especially birds. [External; where hair or feathers are thinnest]	Adult females are bloodsuckers. Vectors of organisms causing avian malaria, fowl pox.	3,9,11
28	*Dermatobia hominis** (human botfly); S. America, W. Indies, tropical N. America	Eggs glued to other arthropods; hatch when suitable host is reached	Dog, swine, mule, cattle, wild animals. [Larvae leave transport arthropod on contact with host; penetrate skin]	Boil-like skin lesions, reduced milk production, damage to hide, decreased growth rate.	8,10, 14
29	*Echidnophaga gallinacea** (sticktight flea); worldwide, especially warm climates	Immature forms associated with nest or sleeping area of host	Poultry, domestic animals, rodents. [External; skin, comb, wattles; around eyes and ears]	Anemia; sometimes death. Adults are bloodsuckers.	3,13, 16
30	*Gasterophilus intestinalis*[3] (horse botfly); worldwide	Pupae in soil; adults attack animals only in daytime	Ass, horse, mule; rarely other animals. [Eggs on foreleg fetlock hairs; larvae (maggots) in mouth, pharynx, stomach]	Extension and infection of wounds.	8,10, 14
31	*Glossina morsitans** (tsetse fly); central Africa	Larvae pass from female when ready to pupate in soil	Cattle, other animals. [External]	Vector of organisms causing cattle and horse nangana, sleeping sickness to man. Adults are bloodsuckers.	11,17
32	*Haematopinus eurysternus*[4] (short-nosed cattle louse); worldwide	None	Cattle. [External; eggs on shaft or at base of hairs]	Hair damage from rubbing; stunting; reduced milk production. Nymphs, adults are bloodsuckers.	11,13
33	*H. suis* (hog louse); worldwide	None	Swine. [External; eggs on hair]	Dermatitis, skin sores, retarded growth. Vector of organism causing swine pox. Nymphs, adults are bloodsuckers.	13
34	*Hypoderma lineatum*[5] (common cattle grub); prevalent in America, Europe, India, northern Asia	Pupae in soil, adults in pastures	Cattle, rarely horse. [Eggs on hair of legs, body; larger larvae form tumor under skin of back]	Skin perforation, hide and flesh damage, milk reduction.	4,11, 13
35	*Melophagus ovinus* (sheep ked); most parts of world	Larvae retained in female until mature; pupae on wool	Sheep, occasionally goat. [External; pupae attached to wool]	Anemia; wool stained, damaged from rubbing. Adults are bloodsuckers.	11,13, 17
36	*Menacanthus stramineus* (chicken body louse); worldwide	None	All domestic fowl. [External; nymphs, adults on skin around vent; eggs attached to feathers]	Scabbing of skin; wasting; reduced egg production.	3,11
37	*Menopon gallinae* (shaft louse); worldwide	None	Chicken, guinea fowl. [External; eggs, nymphs, adults feed on scales, scabs, feathers]	Scaling, scabbing.	3,11

/3/ *G. haemorrhoidalis* (nose botfly) and *G. nasalis* (throat botfly) are similar in many respects to *G. intestinalis*. /4/ Information also applicable to *Linognathus vituli* (long-nosed cattle louse). /5/ Information also applicable to *H. bovis* (northern cattle grub).

continued

	Species (Common Name); Distribution	Free Stage Location	Host [Location and Stage in Host]	Effect on Host	Reference
	(A)	(B)	(C)	(D)	(E)
	Insecta				
38	*Musca domestica* (housefly); worldwide	Immature forms in manure and decayed matter, adults in buildings	Any larger animal with lesions or secretions. [External; adults accidentally ingested by host]	Adults cause decreased productivity of livestock. Vector of several tapeworm species; mechanical vector of many bacterial and protozoan pathogens and helminth eggs.	3,11, 13
39	*Oestrus ovis* (sheep botfly); worldwide	Pupae on ground, adults in warm corners, crevices	Sheep, rarely goat. [Larvae in nasal cavities, sinuses]	Mucosal irritation, nasal discharge, emaciation; sometimes death.	8,11, 13
40	*Phaenicia sericata* (greenbottle fly); worldwide, except S. America and Pacific Islands	Adults free-living, deposit eggs on flesh, soiled wool; pupae in soil	Sheep, goat, other animals. [Larvae on skin, in wounds]	Invasion of wounds, suppuration.	7,11
41	*Phlebotomus papatasii** (sand fly); Mediterranean region, southern Europe, Asia	Immature forms in dark moist places, manure	Warm-blooded animals. [External]	Swelling at site of bite. Vector of organisms causing pappataci fever. Adults are nocturnal bloodsuckers.	11,13, 16
42	*Phormia regina*[6] (black blowfly); worldwide	Pupae in soil, adults in pastures	Sheep, other mammals. [Eggs in hair or wool, larvae in wounds; eggs and larvae also in carcasses]	Extension and infection of wounds.	7,13
43	*Pulex irritans** (human flea); worldwide	Eggs, larvae, and pupae in soil, adults on ground part of time	Man, dog, swine, other animals. [External]	Irritation, poor condition, coat damaged from biting and scratching. Adults are bloodsuckers.	11,17
44	*Simulium* spp.[7] (blackfly); worldwide in temperate to subarctic climates	Immature forms on under sides of stones in moderate-running streams	All warm-blooded animals. [External; on bare parts of head, body, legs; under wings]	Red swelling, vesicles, anemia, toxemia; death. *S. occidentale* and *S. slossonae* are vectors of turkey leucocytozoan disease; some species are vectors of onchocerciasis to man and cattle. Adults are bloodsuckers.	3,11, 13, 16
45	*Siphona irritans* (horn fly); America, Europe	Eggs, maggots in fresh dung, pupae in dung or soil	Cattle, other animals. [External]	Weight loss; milk reduction. Adults are bloodsuckers.	11,13, 17
46	*Stomoxys calcitrans** (stable fly); worldwide	Immature forms in manure and other moist organic waste	Most mammals and birds. [External]	Weight loss; milk reduction. Vector of poultry tapeworms, filariae, spiruroids; mechanical vector of surra. Adults are bloodsuckers.	3,7,11
47	*Tabanus atratus* (black horsefly); N. America	Immature forms in leaves and mud in and near streams, ponds	Most warm-blooded animals. [External]	Vector of organism causing anaplasmosis. Adults are bloodsuckers during day.	13,15
48	*Triatoma sanguisuga*[8] (cone-nose bug); worldwide	All stages commonly found in or close to rodent nests or habitats	All domestic animals, poultry; wood rat usual host. [External]	Swelling, anemia. Nymphs, adults are bloodsuckers.	12,13, 17
49	*Trichodectes canis* (dog-biting louse); worldwide	None	Dog. [External; eggs on hair; nymphs and adults feed on skin]	Scaly skin from rubbing, scratching.	11
50	*Wohlfahrtia vigil** (flesh fly); N. America	Pupae on ground, larvae in woods	Rabbit, mink, guinea pig, young of domestic and wild animals. [Larvae in wounds]	Mild to extensive subcutaneous pustular lesions; occasionally death.	7,11

/6/ *Chrysomya chloropyga* is similar to *P. regina* in its parasitism of sheep. /7/ *S. articum*, *S. occidentale*, *S. ornatum*, *S. vittatum* are the important blackfly pests of livestock. /8/ Sixteen species of *Triatoma* found in the western hemisphere are as important and as widely distributed as *T. sanguisuga*.

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continued

128. ARTHROPOD PARASITES: MAMMALS AND BIRDS

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129. ARTHROPOD PESTS: PLANTS AND PLANT PRODUCTS

	Species	Common Name	Stage[1]	General Distribution	Host	Destructive Activity
	(A)	(B)	(C)	(D)	(E)	(F)
				Arachnida		
1	*Eriophyes pyri*	Pear leaf blister mite	Adult; immature	All pear-growing regions	Pear, apple	Sucking causes blisters on underside of leaves
2	*Rhizoglyphus echinopus*	Bulb mite	Adult; immature	N. America, Europe, Asia	Ornamental bulbs, onion	Bores into bulbs
3	*Steneotarsonemus pallidus*	Cyclamen mite	Adult; immature	N. America, Europe	Greenhouse ornamentals, strawberry	Sucks plant juices, distorts buds and leaves
4	*Tetranychus telarius*	Two-spotted spider mite	Adult; immature	United States, Europe, Africa, Asia, Australia	Cultivated plants	Sucks plant juices, causing loss of vigor, dropping of leaves
				Crustacea		
5	*Porcellio laevis*	Sowbug	Adult; immature	Worldwide	Vegetables, ornamentals	Chews roots, growths near ground
				Insecta		
6	*Acanthoscelides obtectus*	Bean weevil	Larva	Worldwide	Bean, pea, cowpea	Devours inside of bean in field and in storage
7	*Agriotes, Horistonotus, Limonius, Melanotus* spp.	Wireworms	Larva	Worldwide	Truck, cereal, and forage crops	Devours or bores into roots, seeds
8	*Alabama argillacea*	Cotton leafworm	Larva	N. & S. America	Cotton only	Devours leaves
9	*Altica, Phyllotreta* spp.	Flea beetles	Adult; larva[2]	Worldwide	Vegetable crops	Adult makes holes in leaves, larva often feeds on roots
10	*Amphibolips confluenta*	Oak gall wasp	Larva	Worldwide	Oak	Causes galls on oak leaves
11	*Anabrus simplex*	Mormon cricket	Adult; nymph	Western United States	Hay, grain, many plants	Devours hay, grain, leaves of plants
12	*Anasa tristis*	Squash bug	Adult; nymph	N. & Cen. America	Squash, other cucurbits	Sap sucking causes plants to wilt and die

/1/ Destructive stage of arthropod. /2/ Overwinters as adult.

continued

129. ARTHROPOD PESTS: PLANTS AND PLANT PRODUCTS

	Species	Common Name	Stage[1]	General Distribution	Host	Destructive Activity
	(A)	(B)	(C)	(D)	(E)	(F)
	Insecta					
13	*Anthonomus grandis*	Boll weevil	Adult; larva	Southern United States, Mexico	Cotton	Destroys buds, devours squares and bolls
14	*Aphis pomi*	Apple aphid	Adult; nymph	N. America	Apple	Causes wilting
15	*Aspidiotus perniciosis*	San Jose scale	Adult; nymph	Worldwide	Deciduous fruit trees, ornamentals	Secreted toxins cause wilting, kill infested trees
16	*Blissus leucopterus*	Chinch bug	Adult; nymph	N. America	Corn, grains, grasses	Sap sucking causes wilting, death
17	*Carpocapsa pomonella*	Codling moth	Larva	Apple-growing regions of N. & S. America, Europe, Asia, S. Africa, southern Australia	Apple, pear, quince, walnut, apricot, similar fruits	Bores into and destroys fruit, or reduces its value
18	*Cephus pygmaeus*	European wheat stem sawfly	Larva	Northeastern United States, Europe, Near East	Wheat, rye, barley, timothy, other grasses	Mines stems, causing breakage
19	*Ceratitis capitata*	Mediterranean fruit fly	Adult; larva	Mediterranean region, Hawaii, S. Africa, S. America, western Australia	Fruits, vegetables	Adult makes egg punctures, larva burrows through fruit
20	*Choristoneura fumiferana*	Spruce budworm	Larva	Northern United States, Canada	Fir, spruce, hemlock, larch, white pine	Causes partial-to-complete defoliation
21	*Chrysobothris femorata*	Flatheaded apple tree borer	Larva	United States, Canadian fruit-growing areas	Fruit trees, many shade trees	Bores into trunk of weakened trees, branches, twigs; kills tree
22	*Cladius isomerus*	Rose slug	Larva	Worldwide	Rosebush	Skeletonizes and causes browning of leaves
23	*Coccus hesperidum*	Brown scale	Adult; nymph	Worldwide in greenhouses (subtropical spp.)	Citrus, ornamentals	Sap sucking causes plants to die back[3]
24	*Conotrachelus nenuphar*	Plum circulio	Adult; larva	Eastern United States, Canada	Plum, apple, peach, cherry, deciduou stone fruits	Adult punctures fruit, larva feeds within and destroys fruit
25	*Corythuca arcuata*	Oak lace bug		Worldwide	Various trees, shrubs	Speckling of leaves, stunting
26	*Dendroctonus monticolae*	Mountain pine beetle	Adult; larva	Western United States	Western, lodgepole, sugar, ponderosa, white bark, and limber pines	Bores into bark and cambial region; may girdle and kill tree
27	*Diabrotica undecimpunctata*	Spotted cucumber beetle	Adult; larva	N. America	Corn, cucurbits, weeds, grasses, other plants	Larva feeds on roots, adult devours foliage[4]
28	*Diprion hercyniae*	European spruce sawfly	Larva	Europe, northeastern United States, Canada	Spruce	Devours leaves
29	*Drosophila melanogaster*	Fruit fly	Larva	Worldwide	Ripe or decaying fruit	Breeds in ripe fruit
30	*Empoasca fabae*	Potato leafhopper	Adult; nymph	N. & S. America	Potato, alfalfa, bean, celery, other plants	Leaf sucking[5] causes wilting, drying of leaves, stunting
31	*Ephestia kuehniella*	Mediterranean flour moth	Larva	Worldwide	Mill products	Destroys grain products
32	*Epicauta vittata*	Blister beetle	Adult	Worldwide	Potato, legumes	Devours plants

/1/ Destructive stage of arthropod. /3/ Honeydew is formed or excreted. /4/ Also vector of bacterial wilt of cucurbits, and of viral yellow disease of asters. /5/ Also transmits hopperburn disease.

continued

129. ARTHROPOD PESTS: PLANTS AND PLANT PRODUCTS

	Species	Common Name	Stage[1]	General Distribution	Host	Destructive Activity
	(A)	(B)	(C)	(D)	(E)	(F)
				Insecta		
33	*Epilachna varivestis*	Mexican bean beetle	Adult; larva	United States, Mexico	Bean, soybean, cowpea, other legumes	Devours leaves, pods, stems
34	*Epitrix hirtipennis*	Tobacco flea beetle	Adult	Worldwide	Tobacco	Devours leaves, especially those of young plants
35	*Eriosoma lanigerum*	Woolly apple aphid	Adult; nymph	N. & S. America, Europe, S. Africa, Asia, Australia	Apple, pear, elm	Branch and root sucking causes deformed twigs, knotty roots, stunting
36	*Forficula auricularia*	European earwig		Worldwide	Growing plants, stored grain, decayed vegetation	Chewing
37	*Gryllus* spp.	Field cricket	Adult; nymph	N., Cen., & S. America	Hay crops, cotton, linen	Devours hay, plants, cotton, linen
38	*Harmolita tritici*	Wheat jointworm	Larva	Eastern & central United States	Wheat, some grasses	Causes gall in wheat, breaking of stems
39	*Heliothis zea*	Corn earworm	Larva	Worldwide	Cotton, corn, tomato, alfalfa, other plants	Bores into and feeds on bolls, ears, buds; stunts plants, reduces yield
40	*Hylemya antiqua*	Onion maggot	Larva	Europe, N. America	Onion, garlic	Mines out bulbs[3]
41	*Hyphantria cunea*	Fall webworm	Larva	United States, southern Canada	Broadleaf fruit, shade and nut trees	Webs branches, devours foliage
42	*Lampetia equestris*	Narcissus bulb fly	Larva	Europe, N. America	Narcissus, other bulbs	Bores into bulbs
43	*Lasius alienus americanus*	Cornfield ant	Adult	United States	Corn	Symbiotic, with aphids attacking corn roots
44	*Lepisma saccharina*	Silverfish	Adult; nymph	Worldwide	Starchy substances	Devours bookbindings, fabrics, wallpaper
45	*Leptinotarsa decemlineata*	Colorado potato beetle	Adult; larva	N. America, Europe	Potato, tomato, tobacco, eggplant, other solanaceous plants	Devours leaves, terminates growth
46	*Liposcelis divinatorius*	Book louse	Adult; immature	Worldwide	Cereals, vegetables	Contaminates food, destroys bookbindings
47	*Lygus lineolaris*	Tarnished plant bug	Adult; nymph	N. America	Many plants, trees	Leaf sucking and toxins cause bud drop, distortion, stunting
48	*Magicicada septendecim*	Periodical cicada	Adult	Eastern & southern United States	Many deciduous trees, shrubs	Oviposition punctures injure or kill twigs
49	*Malacosoma disstria*	Forest tent caterpillar	Larva	N. America	Aspen, sugar maple, oak, birch, basswood, ash, gum, other trees	Defoliates trees in summer
50	*Megachile latimanus*	Leaf-cutting bee	Adult	Worldwide	Various trees	Cuts off leaf fragments for nests
51	*Melanoplus femurrubrum*	Red-legged grasshopper	Adult; nymph	Worldwide	Hay crops (range and pasture)	Devours hay, grasses, vegetation
52	*Microcentrum rhombifolium*	Broad-winged katydid	Adult; nymph	N. America	Many broad-leaved trees, shrubs	Chews leaves
53	*Murgantia histrionica*	Harlequin cabbage bug	Adult; nymph	Southern United States, Mexico, Cen. America	Cabbage, related crops, other plants	Sap sucking causes plants to wilt, brown, and die
54	*Myzus persicae*	Green peach aphid	Adult; nymph	Warm regions of world	Many trees, shrubs	Leaf sucking causes curling, distortion of leaves[3]

/1/ Destructive stage of arthropod. /3/ Honeydew is formed or excreted.

continued

	Species (A)	Common Name (B)	Stage[1] (C)	General Distribution (D)	Host (E)	Destructive Activity (F)
	Insecta					
55	*Oryzaephilus surinamensis*	Saw-toothed grain beetle	Adult; larva	Worldwide	Grain, grain products, dried fruit	Infests and devours grain, grain products, dried fruit
56	*Oscinella frit*	Frit fly	Larva	N. America, Europe, Asia	Cereals, grasses	Bores into stems, eats central shoots
57	*Paleacrita vernata*	Spring cankerworm	Larva	Eastern United States, Canada	Fruit and shade trees	Defoliates trees in spring
58	*Pectinophora gossypiella*	Pink bollworm	Larva	Southern United States, S. America, Africa, Europe, Asia, Australia	Cotton, okra, other malvaceous plants	Bores into and feeds on squares and bolls, cutting fiber, reducing yield
59	*Peridroma saucia*	Variegated cutworm	Larva	Worldwide	Many plants	Cuts down seedlings, transplants
60	*Philaenus leucophthalmus*	Meadow spittlebug	Nymph	Eastern United States	Legumes, hay crops	Sap sucking causes wilting, stunting, reduced forage yield
61	*Phyllophaga* spp.[6]	June beetle	Adult; larva	N. America	Most plants	Adult defoliates trees; larva devours roots, underground parts
62	*Phylloxera vitifoliae*	Grape phylloxera	Adult; nymph	N. America, Europe	Grape vines	Root and leaf sucking causes galls, eventual death of vines
63	*Phytophaga destructor*	Hessian fly	Larva	Europe, Asia, N. America, New Zealand	Wheat, barley, rye	Feeds on stems, causing breaking and stunting
64	*Pieris rapae*	Imported cabbageworm	Larva	N. America, Asia, Australia, Europe	Cabbage, other crucifers	Devours foliage
65	*Plodia interpunctella*	Indian meal moth	Larva	Worldwide	Grain, grain products, dried fruit, nuts	Destroys and webs grain, grain products; infests fruit, nuts
66	*Plutella maculipennis*	Diamondback moth	Larva	Worldwide	All cruciferous plants	Eats small holes in outer leaves
67	*Popillia japonica*	Japanese beetle	Adult; larva	Eastern United States, Japan, China	Fruit trees, ornamentals, vegetables, grasses	Destroys turf, foliage, blossoms, fruit
68	*Porthetria dispar*	Gypsy moth	Larva	Northeastern United States, Europe, Asia	Most deciduous and evergreen trees, shrubs	Devours leaves
69	*Protoparce quinquemaculata*	Tomato hornworm	Larva	N. & S. America, Europe, Hawaii	Tomato, tobacco, other solanaceous plants	Devours foliage
70	*Pseudaletia unipuncta*	Armyworm	Larva	Worldwide	Grains, grasses, some legumes	Devours foliage
71	*Pseudococcus citri*	Mealybug	Adult; nymph	Tropical & subtropical areas	Citrus, ornamental plants	Sap sucking causes plants to die back[3]
72	*Psila rosae*	Carrot rust fly	Larva	Europe, northern N. America	Carrot, celery, umbelliferous plants	Bores into and eats fibrous roots
73	*Psyllia pyricola*	Pear psylla	Adult; nymph	Europe, United States	Pear	Leaf sucking causes leaf drop[3]
74	*Pyrausta nubilalis*	European corn borer	Larva	Eastern United States, Europe, Asia	Corn is main host; also many vegetables, weeds, ornamentals	Bores into stalks and ears, causing breakage, reduced yield and quality
75	*Ramosia tipuliformis*	Currant borer	Larva	N. America, Asia, Europe, Australia	Currant, gooseberry, black elder, sumac	Burrows through canes
76	*Reticulitermes flavipes*	Eastern subterranean termite	Adult; nymph	Eastern United States	Wood, dead wood, cellulose products	Riddles, weakens, destroys wood and cellulose materials

/1/ Destructive stage of arthropod. /3/ Honeydew is formed or excreted. /6/ Other important June beetles belong to *Melolontha* and *Polyphylla* spp.

continued

129. ARTHROPOD PESTS: PLANTS AND PLANT PRODUCTS

	Species	Common Name	Stage[1]	General Distribution	Host	Destructive Activity
	(A)	(B)	(C)	(D)	(E)	(F)
				Insecta		
77	*Rhagoletis pomonella*	Apple maggot	Larva	Northeastern & north central United States	Apple, blueberry	Bores into and destroys fruit
78	*Sanninoidea exitiosa*	Peach tree borer	Larva	All peach-growing areas	Peach, other stone-fruit trees	Bores into trunk at ground-level roots, girdles tree trunk, kills tree
79	*Saperda candida*	Round-headed apple tree borer	Larva	Eastern United States, Canada	Apple, pear, quince trees	Bores into trunk
80	*Schistocerca gregaria*[7]	Desert locust	Adult; nymph	India, Iran, Arabia, N. Africa	Many plants	Chews leaves
81	*Sitophilus oryza*	Rice weevil	Adult; larva	Worldwide	Stored grains, cereal products	Larva grows in kernels, destroys stored grain
82	*Sminthurus viridis*	Lucerne flea	Adult; immature	Europe, Australia	Legumes	Surface feeding causes scorching of leaves
83	*Spissistilus festinus*	Three-cornered alfalfa bug	Adult	Worldwide	Alfalfa	Stunting
84	*Tenebrio molitor*	Yellow mealworm	Larva	Worldwide	Grain products, refuse	Destroys grain, grain products
85	*Tenebroides mauritanicus*	Cadelle	Adult; larva	Worldwide	Stored grain, grain products	Infests and destroys grain, grain products
86	*Thermobia domestica*	Firebrat	Adult; nymph	Worldwide	Starchy substances	Devours bookbindings, fabrics, wallpaper
87	*Thrips tabaci*	Onion thrips	Adult; larva; nymph	N. & S. America, Europe, Asia, S. Africa, Australia	Onion, bean, cabbage, tomato, cotton	Sap sucking causes leaves and buds to pucker and silver
88	*Thyridopteryx ephemeraeformis*	Bagworm	Larva	Eastern United States	Cedar, other trees	Devours foliage
89	*Trialeurodes vaporariorum*	Greenhouse whitefly	Nymph	Worldwide	Most plants	Leaf sucking causes wilting[3]
90	*Tribolium confusum*	Confused flour beetle	Adult; larva	Worldwide	Flour, grain products	Infests and contaminates flour, mixes, bread
				Symphyla		
91	*Scutigerella immaculata*	Garden symphylid	Adult; immature	N. & S. America, Europe, Africa	Garden plants, flowers	Chews tender plants, rootlets
				Diplopoda		
92	*Julus heserus*	Millipede	Adult; immature	Worldwide	Vegetables, ornamentals	Chews young roots, stems

/1/ Destructive stage of arthropod. /3/ Honeydew is formed or excreted. /7/ Has a migratory phase.

Contributors: (a) Allen, William W., (b) Stanley, W. W., and Dozier, Byrd K.

References: [1] Craighead, F. C. 1949. U.S. Dept. Agr. Misc. Publ. 657. [2] Essig, E. O. 1958. Insects and mites of western North America. Macmillan, New York. [3] Imms, A. D., O. W. Richards, and R. G. Davies. 1960. A general textbook of entomology. Ed. 9. E. P. Dutton, New York. [4] Little, W. A. 1963. General and applied entomology. Ed. 2. Harper and Row, New York. [5] Metcalf, C. L., and W. P. Flint. 1962. Destructive and useful insects, their habits and control. Ed. 4. McGraw-Hill, New York. [6] Peairs, L. M., and R. H. Davidson. 1956. Insect pests of farm, garden, and orchard. Ed. 5. Chapman and Hall, New York. [7] Pfadt, R. E. 1962. Fundamentals of applied entomology. Macmillan, New York. [8] U.S. Department of Agriculture. 1952. Insects. Yearbook of agriculture. U.S. Govt. Printing Office, Washington, D. C.

Part I.

	Species (Common Name)	Geographic Distribution	Reservoir Host of Definitive Stage	Vector, or Obligate Host Other than Man	Infective Stage
	(A)	(B)	(C)	(D)	(E)
			Nematoda		
1	*Ancylostoma braziliense* (hookworm)	Limited distribution in warm climates	Cat, dog	None	Filariform larva
2	*A. duodenale* (hookworm)	Tropical & subtropical Africa, Asia, Europe, United States; western S. America	None	None	Filariform larva
3	*Ascaris lumbricoides* (large roundworm)	Worldwide; more common in warm climates	Swine ?	None	Fully embryonated egg
4	*Brugia malayi* (Malayan filarial worm)	Warm climates in Asia	Cat, monkey	Mosquito *(Armigeres, Mansonia)*	Filariform larva
5	*Dracunculus medinensis* (guinea worm)	Warm climates of eastern hemisphere	Fur-bearing mammals	*Cyclops*	3rd stage larva in *Cyclops*
6	*Enterobius vermicularis* (pinworm)	Worldwide; common in children	None	None	Fully embryonated egg
7	*Loa loa* (African filarial worm)	Tropical Africa	None	Mango fly *(Chrysops)*	Filariform larva
8	*Necator americanus* (hookworm)	Warm climates	None	None	Filariform larva
9	*Onchocerca volvulus* (convoluted filarial worm)	Tropical Africa, Mexico, Guatemala, eastern Venezuela, Dutch Guiana ?	None	Blackfly *(Simulium)*	Filariform larva
10	*Strongyloides stercoralis* (intestinal threadworm)	Warm, moist climates	Chimpanzee, dog	None	Filariform larva
11	*Trichinella spiralis* (trichina worm)	Worldwide; common in United States	Bear, swine, walrus	None	Larva encysted in pork muscle
12	*Trichuris trichiura* (human whipworm)	Warm, moist climates	Ape, monkey; swine ?	None	Fully embryonated egg
13	*Wuchereria bancrofti* (Bancroft's filarial worm)	Warm climates	None	Mosquito (*Aedes*, *Culex*, etc.)	Filariform larva
			Cestoda		
14	*Diphyllobothrium latum* (fish tapeworm)	North temperate & subarctic zones; lakes in Argentina, Chile	Bear, cat, dog	*Cyclops, Diaptomus*; freshwater fish	Sparganum larva in fish flesh
15	*Dipylidium caninum* (double-pored dog tapeworm)	Warm climates	Cat, dog	Cat flea, dog flea, human flea	Larva in hemocoel of dog flea
16	*Echinococcus granulosus* (hydatid tapeworm)	Worldwide; common in southern S. America	Dog, wild relatives	Cattle, sheep, swine (alternating with dog)	Eggs in dog's excreta
17	*E. multiocularis* (multiocular hydatid tapeworm)	North temperate zones	Wild canids	Small rodents	Eggs in excreta of wild canids
18	*Hymenolepis diminuta* (rat tapeworm)	Warm & temperate climates	Mouse, rat	Grain beetle, meal moth, rodent flea, etc.	Larva in hemocoel of insect
19	*H. nana* (dwarf tapeworm)	Warm & temperate climates	Mouse, rat	None; may develop in grain beetle	Egg
20	*Taenia saginata* (beef tapeworm)	Worldwide	None	Cattle	Cysticercus larva in beef
21	*T. solium* (pork tapeworm)	Worldwide	None	Swine	Cysticercus larva in pork; egg

/1/ By direct or indirect contact with body excreta containing parasite. /2/ From proboscis of insect vector at time mouth.

PARAPARASITES: MAMMALS AND BIRDS

MAN

In Man				Identification of Parasite	
Portal of Infection	Immature Stage	Definitive Stages: Primary Site	Definitive Stages: Secondary Site		
(F)	(G)	(H)	(I)	(J)	
Nematoda					
Skin[1]	Larva migrates from skin via blood and lungs to epiglottis and GI tract	Attached to small intestine	None	Egg in feces; larva in cutaneous tunnels	1
Skin[1]	Larva migrates from skin via blood and lungs to epiglottis and GI tract	Attached to small intestine	None	Egg in feces	2
Mouth[1]	Larva migrates	Lumen of small intestine	Various viscera	Egg in feces	3
Skin[2]	Larva migrates in lymphatics	Lymphatics of lower trunk	Lymphatics of upper trunk	Microfilaria (sheathed) in peripheral blood (nocturnal and subperiodic)	4
Mouth[3]	In viscera	Gravid female migrates to skin	None known	Gravid female in ruptured skin blister	5
Mouth[1]	In transit down small intestine	Attached to cecum, appendix	Female genital tract, perianal folds	Egg or adult in anal swab, anus	6
Skin[2]	Migrates in subcutaneous tissues	Migrates in subcutaneous tissues	Orbit, conjunctiva of eye	Microfilaria (sheathed) in diurnal blood	7
Skin[1]	Larva migrates	Attached to small intestine	None	Egg in feces	8
Skin[2]	Larva in skin, may invade eye tissues	Adult in subcutaneous nodules; larva in skin, may invade eye tissues	None known	Microfilaria (unsheathed) in skin biopsy	9
Skin[1]	Larva migrates	Within intestinal mucosa	Lungs	Larva in feces or duodenal aspirate	10
Mouth[3]	Enters duodenal mucosa	In duodenal mucosa	Larva migrates; encysts in striped muscle	Larva in compressed or digested muscle	11
Mouth[1]	In transit down small intestine	Attached to cecum, appendix	Colon, rectum	Egg in feces	12
Skin[2]	Larva migrates in lymphatics	Lymphatics of lower trunk, legs	Lymphatics of upper trunk	Microfilaria (sheathed) in blood (usually nocturnal)	13
Cestoda					
Mouth	Develops in small intestine	Attached to small intestine	None known	Egg in feces	14
Mouth	Develops in small intestine	Attached to small intestine	None	Proglottid in feces	15
Mouth	Develops in liver, lungs	Attached to small intestine	Hydatid cysts in viscera	Hydatic cysts with scolices during aspiration or exploratory operation	16
Mouth	Develops unconfined in liver	Attached to small intestine	Hydatid cysts in liver	Hydatid cysts with scolices during postmortem examination	17
Mouth	Develops in duodenum, small intestine	Attached to small intestine	None	Proglottid or egg in feces	18
Mouth	Develops in duodenal villi	Attached to small intestine	None known	Egg in feces	19
Mouth	Develops in small intestine	Attached to small intestine	None known	Proglottid or egg in feces	20
Mouth	Develops in small intestine	Attached to small intestine	Cysticercus larva in various stages	Proglottid or egg in feces	21

of skin puncture to obtain blood or tissue juice from host. /3/ From infected food or contaminated water taken into

continued

	Species (Common Name)	Geographic Distribution	Reservoir Host of Definitive Stage	Vector, or Obligate Host Other than Man	Infective Stage
	(A)	(B)	(C)	(D)	(E)
	Trematoda				
22	*Clonorchis sinensis* (Chinese liver fluke)	Sino-Japanese & Indo-Chinese areas	Many fish-eating mammals	Freshwater fishes, snail	Larva encysted in flesh of freshwater fish
23	*Fasciola hepatica* (liver fluke)	Sheep-raising countries	Herbivores	Snail, moist vegetation	Larva encysted on water plants
24	*Fasciolopsis buski* (intestinal fluke)	Oriental countries	Swine	Snail, water plants	Larva encysted on water plants
25	*Paragonimus westermani* (lung fluke)	Sino-Japanese areas, Southwest Pacific islands; northern S. America	Cat, dog, swine, other animals	Crab, crayfish, and snail; sputum of man	Larva encysted in soft tissues of crabs, crayfish
26	*Schistosoma haematobium* (human blood fluke)	Africa, Near East, Middle East, southern Portugal	Gerbil	Bulinid snail	Cercaria free in freshwater
27	*S. japonicum* (blood fluke)	China, Japan, Philippines, Formosa, Celebes	Many mammals	Oncomelaniid snail	Cercaria free in freshwater
28	*S. mansoni* (blood fluke)	Africa, Arabia, Brazil, Guianas, Venezuela, West Indies	Monkey (rarely)	Planorbid snail	Cercaria free in freshwater
	Protozoa				
29	*Balantidium coli*	Worldwide; most common in warm climates	Monkey (?), swine	None	Mature cyst
30	*Entamoeba coli*	Worldwide; most common in warm climates	Monkey ?	None	Four-nucleate cyst
31	*E. histolytica*	Worldwide; most common in warm climates	Dog, monkey; rat ?	None	Four-nucleate cyst
32	*Giardia lamblia*	Worldwide; most common in warm climates	None	None	Four-nucleate cyst
33	*Leishmania braziliensis*	Western hemisphere from southern Mexico to northern Argentina	Dog, possibly other mammals	Sand fly (*Phlebotomus*)	Leptomonad
34	*L. donovani*	China, India, Africa, Mediterranean area, S. America	Dog, rodents	Sand fly (*Phlebotomus*)	Leptomonad
35	*L. tropica*	Western India, Middle East, Near East, N. Africa	Dog, rodents	Sand fly (*Phlebotomus*)	Leptomonad
36	*Plasmodium falciparum, P. malariae, P. vivax*	Temperate or warm climates	None	Mosquito (*Anopheles*)	Sporozoite
37	*Toxoplasma gondii*	Worldwide	Many mammals and birds	None known	Trophozoite
38	*Trichomonas vaginalis*	Worldwide (relatively common in both sexes)	None	None	Trophozoite (only stage known)
39	*Trypanosoma cruzi*	Western hemisphere from United States to northern Argentina	Many mammals	Triatomid bug	Metacyclic trypanosome
40	*T. gambiense*	Western & central Africa	Cattle ?	Tsetse fly (*Glossina*)	Metacyclic trypanosome
41	*T. rhodesiense*	Central & eastern Africa	Mammals, wild game	Tsetse fly (*Glossina*)	Metacyclic trypanosome

/1/ By direct or indirect contact with body excreta containing parasite. /2/ From proboscis of insect vector at time mouth. /4/ In contact with infested water. /5/ From feces of insect vector while feeding on blood or tissue juice of

Contributor: Faust, Ernest Carroll

Reference: Faust, E. C., Beaver, P. C., and Jung, R. C. 1962. Animal agents and vectors of human disease. Ed. 2.

PARASITES: MAMMALS AND BIRDS

MAN

In Man				Identification of Parasite	
Portal of Infection	Immature Stage	Definitive Stages: Primary Site	Definitive Stages: Secondary Site		
(F)	(G)	(H)	(I)	(J)	
Trematoda					
Mouth[3]	In transit from duodenum to bile ducts	Distal bile ducts	Pancreatic ducts (rare)	Egg in feces	22
Mouth[3]	In transit from duodenum to bile ducts	Proximal bile ducts	Abdominal wall (?), lungs, brain	Egg in feces	23
Mouth[3]	Develops in duodenum, jejunum	Attached to duodenum, jejunum	None	Egg in feces	24
Mouth[3]	In transit from duodenum to lungs	Lungs, near bronchioles	Abdominal viscera, brain	Egg in sputum or feces	25
Skin[4]	Migrates in blood vessels	Vesical venous plexus	Pelvic organs, rectum, lungs, central nervous system	Egg in urine or feces	26
Skin[4]	Migrates in blood vessels	Mesenteric venules	Liver, lungs, brain	Egg in feces	27
Skin[4]	Migrates in blood vessels	Mesenteric venules	Liver, lungs, brain	Egg in feees	28
Protozoa					
Mouth[1]	None described	Wall of large intestine	None	Trophozoite or cyst in feces	29
Mouth[1]	None described	Lumen of large intestine	None	Trophozoite or cyst in feces	30
Mouth[1]	None described	Wall of large intestine	Other viscera, skin	Trophozoite or cyst in feces, visceral abscesses, or skin abscesses	31
Mouth[1]	None described	Duodenal crypts	Gallbladder ?	Trophozoite or cyst in feces	32
Skin[2]	None described	Skin	Mucous membranes	Leishmanial stage in reticuloendothelial cells, skin, or viscera; Leptomonad stage in culture	33
Skin[2]	None described	Skin	Reticuloendothelium (fundamental)	Leishmanial stage in reticuloendothelial cells, skin, or viscera; Leptomonad stage in culture	34
Skin[2]	None described	Skin	Mucous membranes (rare)	Leishmanial stage in reticuloendothelial cells, skin, or viscera; Leptomonad stage in culture	35
Skin[2]	Schizonts in hepatic parenchyma	Exoerythrocytic foci	Erythrocytes	Trophozoite, schizont, or gametocyte in blood	36
Unknown	None known	Reticuloendothelium, many parenchymal cells	Brain, retina	Trophozoite, pseudocyst, or cyst in focal areas of necrosis	37
Vulva[1] or urethra	None described	Vaginal fold	Bladder	Trophozoite in urine or vaginal smear	38
Skin[5], conjunctiva	None described	Skin	In tissues, blood	Trypanosomal stage in blood or tissues; Leishmanial stage in macrophage; Crithidial stage in culture	39
Skin[2]	None described	Skin	Blood, lymph nodes, central nervous system	Trypanosomal stage in blood, gland juice, or spinal fluid	40
Skin[2]	None described	Skin	Blood, lymph nodes, central nervous system	Trypanosomal stage in blood, gland juice, or spinal fluid	41

of skin puncture to obtain blood or tissue juice from host. /3/ From infected food or contaminated water taken into host.

Lea and Febiger, Philadelphia.

continued

Part II. VERTEBRATES

	Species (Common Name)	Geographic Distribution	Intermediate Host
	(A)	(B)	(C)
	Acanthocephala		
1	*Macracanthorhynchus hirudinaceus* (thorny-headed worm)	Worldwide	Beetle (*Cotinis*, *Phyllophaga*)
	Nematoda		
2	*Ancylostoma caninum* (dog hookworm)	Worldwide	None
3	*Ascuridia galli* (large roundworm of chicken)	Worldwide	None
4	*Ascaris lumbricoides suum* (large roundworm)	Worldwide	None
5	*Dictyocaulus filaria* (thread lungworm of sheep)	Worldwide	None
6	*D. viviparus* (lungworm of cattle)	Worldwide	None
7	*Dirofilaria immitis* (dog heartworm)	Worldwide	Mosquito (*Aedes*, *Anopheles*, *Culex*)
8	*Haemonchus contortus* (twisted stomach worm)	Worldwide	None
9	*Heterakis gallinae* (cecal worm)	Worldwide	None
10	*Metastrongylus elongatus* (swine lungworm)	Worldwide	Earthworm (several genera including *Eisenia*, *Lumbricus*)
11	*Oesophagostomum columbianum* (sheep nodular worm)	Worldwide	None
12	*Ostertagia circumcinta* (brown stomach worm of sheep)	Worldwide	None
13	*O. ostertagi* (brown stomach worm of cattle)	Worldwide	None
14	*Parascaris equorum* (large roundworm)	Worldwide	None
15	*Strongyloides stercoralis* (intestinal threadworm)	Cosmopolitan in warm climates	None
16	*Strongylus vulgaris* (single-toothed strongyle)	Worldwide	None
17	*Toxascaris leonina* (dog roundworm)	Worldwide	None
18	*Toxocara canis* (dog roundworm)	Worldwide	None
19	*Trichinella spiralis* (trichina worm)	Worldwide	Same individual both definitive and intermediate host[2]
20	*Trichostrongylus axei* (minute stomach worm)	Worldwide	None
21	*T. colubriformis* (hairworm)	Worldwide	None
22	*Trichuris suis* (swine whipworm)	Worldwide	None
23	*T. vulpis* (dog whipworm)	Worldwide	None
	Cestoda		
24	*Dibothriocephalus latus* (fish tapeworm)	N. America, Argentina, Chile, Europe, Australia, Manchuria, Siberia, Japan	First: copepod (*Cyclops*, *Diaptomus*); second: fish
25	*Dipylidium caninum* (double-pored dog tapeworm)	Worldwide	Flea (*Ctenocephalides*, *Pulex*); louse (*Trichodectes*)
26	*Echinococcus granulosus* (hydatid tapeworm)	N. & S. America, Europe, Iceland, Australia, northern Asia, Africa	Camel, cow, dog, goat, horse, monkey moose, rabbit, sheep, rodents, etc.[1]
27	*Hymenolepis carioca* (thread tapeworm)	Worldwide	Many beetles (*Anisotarsus*, *Aphodius*, and others); stable fly (*Stomoxys*)
28	*Moniezia expansa* (sheep tapeworm)	Worldwide	Grass mite (*Galumna*, *Oribatula*, and others)

/1/ Also man. /2/ Reservoir host: swine for man.

PARASITES: MAMMALS AND BIRDS
OTHER THAN MAN

Definitive Host (D)	Primary Location in Definitive Host (E)	Disease or Disorder (F)	
	Acanthocephala		
Swine	Small intestine	Nodule formation	1
	Nematoda		
Cat, coyote, dog, fox[1]	Small intestine	Anemia, emaciation, skin reactions	2
Chicken, goose, guinea fowl, turkey, wild birds	Small intestine	Emaciation	3
Swine[1]	Small intestine	Pneumonia, abdominal discomfort and obstruction, emaciation	4
Goat, sheep, some wild ruminants	Bronchi, bronchioles	Catarrhal inflammation, coughing, emaciation	5
Cattle, deer	Bronchi, bronchioles	Catarrhal inflammation, coughing, emaciation	6
Cat, coyote, dog, fox, wolf	Heart, pulmonary artery; microfilariae in blood	Emaciation, cough, edema, dyspnea	7
Cattle, goat, sheep, other ruminants	Abomasum	Anemia, emaciation	8
Chicken, guinea fowl, pheasant, quail, turkey, other birds	Cecum	None; egg carries *Histomonas*	9
Swine	Bronchi, bronchioles	Bronchitis, pneumonia; transmits swine influenza virus	10
Antelope, goat, sheep	Large intestine; larvae in nodules throughout intestine	Diarrhea, emaciation, nodules in intestine	11
Goat, sheep	Abomasum	Anemia, emaciation	12
Cattle, sheep, rarely horse	Abomasum	Anemia, edema, emaciation	13
Horse, other equids	Small intestine	Pneumonia, digestive disturbances, emaciation	14
Cat, dog, fox[1]	Small intestine mucosa	Diarrhea	15
Horse, other equids	Large intestine	Anemia, edema, digestive disturbances, emaciation; larvae form aneurysms in anterior mesenteric arteries	16
Cat, dog, fox, wild canids and felids	Small intestine	Emaciation, poor growth	17
Coyote, dog, fox	Small intestine	Emaciation, poor growth	18
Badger, rat, swine, many other mammals[1]	Small intestine; larvae in muscles	Trichinosis, toxemia, muscle pains	19
Cattle, deer, goat, horse, sheep, swine[1]	Abomasum	Emaciation	20
Antelope, camel, cattle, goat, sheep	Small intestine	Emaciation	21
Ape, monkey, swine[1]	Cecum	Toxemia	22
Dog, fox	Cecum	Emaciation, low-grade inflammation	23
	Cestoda		
Cat, dog, fox, polar bear, other fish-eating mammals[1]	Small intestine	Toxemia, anemia	24
Cat, dog, fox, wolf, other carnivores[1]	Small intestine	Enteritis, anal pruritus	25
Dog, fox, wolf, other canids	Small intestine	Slight, if any, enteritis; hydatid cysts in liver, lungs, etc., of intermediate hosts cause serious damage	26
Chicken, quail, turkey	Small intestine	Slight damage	27
Cattle, goat, sheep, other ruminants	Small intestine	Emaciation	28

continued

	Species (Common Name)	Geographic Distribution	Intermediate Host
	(A)	(B)	(C)
	Cestoda		
29	***Raillietina cesticillus*** **(broad-headed tapeworm)**	Worldwide	Ground and dung beetles (several genera)
30	***Taenia pisiformis*** **(dog tapeworm)**	Worldwide	Hare, rabbit, rat, squirrel
	Trematoda		
31	***Fasciola hepatica*** **(liver fluke)**	Worldwide	Freshwater snail *(Fossaria, Galba, Lymnaea, Pseudosuccinea,* and others)[3]
32	*Nanophyetus salmincola* ("salmon-poisoning" fluke)	Pacific Northwest	First: snail *(Goniobasis)*; second: fish (usually *Salmo*, also *Oncorhynchus, Salvelinus)*
	Protozoa		
33	*Babesia bigemina*	N., Cen., & S. America, Europe, Australia, Asia, Africa, Pacific islands	Tick *(Boophilus, Rhipicephalus)*
34	*Balantidium coli*	Worldwide	None
35	*Eimeria ahsata*	Worldwide	None
36	*E. necatrix*	Worldwide	None
37	*E. tenella*	Worldwide	None
38	*E. zurnii*	Worldwide	None
39	*Histomonas meleagridis*	Worldwide	None; transmitted in *Heterakis gallinae* eggs[4]
40	*Iodamoeba buetschlii*	Worldwide	None
41	*Isospora bigemina*	Worldwide	None
42	*Leishmania donovani*	Cen. & S. America, Mediterranean basin, Balkan states, Near East, India, China, Russia, Africa	Sand fly *(Phlebotomus)*[5]
43	*L. tropica*	Mediterranean basin, Near East, India, Russia, Africa	Sand fly *(Phlebotomus)*[5]
44	*Theileria annulata*	Southern Europe, Asia, Africa	Tick *(Hyalomma)*
45	*Toxoplasma gondii*	Worldwide	None ?[7]
46	*Trichomonas gallinae*	Worldwide	None
47	*Tritrichomonas foetus*	Worldwide	None
48	*Trypanosoma brucei*	Africa	Tsetse fly *(Glossina)*[8]
49	*T. cruzi*	Southwestern United States, Cen. & S. America	Kissing bug *(Panstrongylus, Triatoma)*; assassin bug *(Rhodinus)*[9]
50	*T. evansi*	Cen. & S. America, southeastern Europe, Asia, Africa	Stable fly *(Stomoxys)*, horsefly *(Tabanus)*[9]

/1/ Also man. /3/ Reservoir host: wild rabbit for ruminants. /4/ Reservoir hosts: chicken and wild gallinaceous
/7/ Reservoir hosts: wild rodents. /8/ Reservoir hosts: wild ruminants and equids. /9/ Reservoir hosts: wild ani-

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PARASITES: MAMMALS AND BIRDS
OTHER THAN MAN

Definitive Host	Primary Location in Definitive Host	Disease or Disorder	
(D)	(E)	(F)	
Cestoda			
Chicken, pheasant, quail, turkey, wild galliforms	Small intestine	Slight damage	29
Cat, coyote, dog, fox, wolf	Small intestine	Slight, if any, enteritis; anal pruritus	30
Trematoda			
Cat, dog, elephant, hare, horse, kangaroo, rabbit, swine, rodents; cattle, goat, sheep, other ruminants[1]	Proximal bile duct	Liver necrosis, cirrhosis, calcification of bile ducts	31
Coyote, dog, fox, lynx, mink, raccoon	Small intestine	Enteritis; parasite carries *Neorickettsia helminthoeca*, the cause of "salmon poisoning"	32
Protozoa			
Cattle	Erythrocytes	Fever, anemia, hemoglobinuria; causes Texas fever	33
Monkey, swine[1]	Large intestine	Secondary invader of mucosa	34
Goat, sheep	Small intestine cells	Diarrhea, emaciation	35
Chicken	Small intestine cells	Hemorrhagic enteritis	36
Chicken	Cecal cells	Hemorrhagic enteritis	37
Cattle	Intestinal cells	Enteritis, hemorrhagic dysentery	38
Chicken, partridge, peafowl, pheasant, quail, ruffed grouse	Cecum, liver	Enterohepatitis, necrosis, ulceration	39
Monkey, swine[1]	Large intestine	None	40
Cat, dog, fox, mink	Small intestine cells	Diarrhea	41
Dog[1]	Reticuloendothelial system	Kala azar; reticuloendotheliosis, splenomegaly	42
Dog, gerbil[1]	Cutaneous tissues	Oriental sore, skin ulcer	43
Cattle, zebu	Lymphocytes, erythrocytes	Fever, anemia, emaciation	44
Birds; cat, dog, rodents, other mammals[1]	Endothelial cells, leucocytes	Chorioretinitis, cerebral calcification, pneumonia	45
Chicken, dove, hawk, pigeon, turkey	Crop, esophagus	Caseous nodules, necrosis	46
Cattle	Uterus, genital system, prepucial and penile membranes	Abortion, estrus irregularity, macerated fetus, contaminated semen	47
Cat, dog, swine, equids, ruminants	Blood	Anemia, emaciation, edema; causes nagana	48
Armadillo, bat, cat, dog, monkey, opossum, wood rat[1]	Blood, myocardium, and other tissues	Chagas' disease; tissue destruction	49
Cat, dog, elephant, swine, equids, ruminants	Blood	Urticaria, edema, emaciation; surra	50

birds for turkey. /5/ Reservoir host: dog for man. /6/ Reservoir hosts: dog, gerbil and *Rhombomys* for man. mals.

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Most of the nematode parasites of plants are found in close association with the roots, or in the upper 16 inches of ceous forms, also found in the soil, by the presence of a protrusile spear or stylet used to puncture and feed on plant others live only in the ocean, and many are parasites of animals and man.

	Species (Common Name)	Geographic Distribution[1]	Host[2]
	(A)	(B)	(C)
1	*Anguina* spp. (wheat gall eelworm)	N. America, Europe	Several *Agrostis* species; other grasses and cereals
2	*A. tritici* (wheat nematode)	Southern Atlantic states, Europe, southern & eastern Asia, Egypt, Australia	Emmer, rye, spelt, wheat
3	*Aphelenchoides besseyi* (summer crimp nematode of strawberry)	Southeastern United States (Maryland to Texas)	Rice, strawberry
4	*A. cocophilus* (coconut palm nematode)	West Indies, Honduras, Panama, British Guiana, Venezuela	Coconut, date, and oil palms
5	*A. fragariae* (spring crimp nematode of strawberry)	Massachusetts, Connecticut, Delaware, Maryland, Europe	Strawberry
6	*A. ritzema-bosi* (chrysanthemum nematode)	N. America, Europe	About 50 different plants, including chrysanthemum, larkspur, phlox, strawberry, verbena, zinnia
7	*Belonolaimus gracilis* (sting nematode)	Southern Atlantic states	Bean, beet, cabbage, celery, citrus, corn, cotton, cowpea, grass, millet, okra, onion, peanut, pine seedling, soybean, strawberry
8	*Criconemoides* spp. (ring nematode)	Widespread	Many plants; reported as injuring peach trees and peanut vines
9	*Ditylenchus destructor* (potato rot nematode)	Idaho, Wisconsin, Prince Edward Island, Europe	Carrot, iris, potato, sweet potato, tulip
10	*D. dipsaci* (bulb and stem nematode)	Widespread in temperate zones	Over 300 different plants, including alfalfa, clover, hyacinth, iris, narcissus, oats, onion, phlox, potato
11	*Dolichodorus heterocephalus* (awl nematode)	Florida, Georgia, North Carolina, Michigan	Bean, celery, Chinese water chestnut, corn, tomato; many other plants growing in wet locations
12	*Helicotylenchus* spp., *Rotylenchus* spp. (spiral nematode)	Widespread in sub-tropical and tropical regions	Many plants, including bean, cotton, cowpea, grass, pineapple, soybean, and ornamentals
13	*Heterodera glycine* (soybean cyst nematode)	Midwestern & southern United States, China, Japan	Adzuki bean, annual lespedeza, kidney bean, snap bean, soybean, vetch
14	*H. rostochiensis* (golden nematode of potato)	Long Island, N. Y.; Bolivia, Peru, Europe	Potato, tomato, several other solanaceous plants
15	*H. schachtii* (sugar beet nematode)	United States, Canada, Europe, Australia	Over 100 plants, including broccoli, cabbage, cauliflower, kale, mangel-wurzel, mustard, rutabaga, sugar beet, table beet, turnip
16	*Hoplolaimus tylenchiformis* (lance nematode)	N. America, Philippines, Europe	Many plants, including corn, cotton, pine tree, sugarcane, St. Augustine and other lawn grasses

/1/ Information on geographic distribution of plant parasitic nematodes is fragmentary and incomplete, even for the genus vary in ability to attack plants; some have a rather wide host range, others are highly host-specific, attacking stage of development of the host and parasite. /4/ Symptoms of nematode damage are often difficult to distinguish find the nematode in the diseased tissue or soil adjacent to the roots of affected plants.

soil formerly occupied by the roots. In general, plant nematodes can be distinguished from saprophagous or preda-
cells. The soil is not the only habitat, however, for nematodes: some live in freshwater rivers, lakes, and ponds,

Feeding Habits[3]	Symptoms[4]	Control	Reference	
(D)	(E)	(F)	(G)	
Larvae, ectoparasites around growing point; adults, endoparasites of flower primordia	Abnormal flowers developing into galls	Crop rotation; planting of gall-free seed	21,24	1
Larvae, ectoparasites around growing point; adults, endoparasites of flower primordia	Stunted plants, distorted foliage, galls instead of seed	Planting of gall-free seed (galls may be removed by salt brine flotation or mechanical separators)	18, 34	2
Vagrant ectoparasites of buds and growing point between young developing leaves	Small, crinkled, distorted foliage	Setting of new beds with uninfested plants; hot-water treatment or methyl bromide fumigation for rice seed	13,22	3
Vagrant endoparasites of roots, trunk (near periphery), leaf petioles	Disintegration of trunk tissues (causing "red ring") and of root cortex	No established control methods	40	4
Vagrant ectoparasites of buds between young developing leaves	Small, crinkled, distorted foliage	Setting of new beds with uninfested plants	5,13	5
Vagrant endoparasites of buds and foliage	Crinkled, distorted leaves and leaf spots	Hot-water treatment of dormant plants; parathion sprays	23,25,26, 46	6
Vagrant ectoparasites of root tips, sides of succulent roots, other underground parts	Devitalized root tips, root lesions, causing many short stubby branched roots, severely stunted plants	Soil fumigation	15,16,31, 39	7
Semi-sedentary ectoparasites of roots, other underground parts	Small lesions, stunting of plant	Soil fumigation	11,37	8
Vagrant endoparasites of tubers and, to some extent, of roots	Destruction of tuber tissues causing sunken areas, followed by rot	Crop rotation; planting of clean seed; soil fumigation	4,52	9
Vagrant endoparasites of bulbs, stems, leaves, occasionally roots	Twisting, wrinkling, distortion of stems and flowers; necrosis and destruction of bulb tissues	Hot-water treatment of bulbs, corms; crop rotation; field sanitation; methyl bromide fumigation of infected onion and clover seeds; planting of resistant varieties	1,20,48	10
Vagrant ectoparasites of root tips, sides of succulent roots	Devitalized root tips, small lesions on sides of roots; sometimes extensive root destruction	Soil fumigation	41,50	11
Vagrant ectoparasites, occasionally endoparasites of roots and other underground parts	Stunting of plant from retarded root growth; lesions may occur	Soil fumigation	29,47	12
Sedentary parasites of roots, internal in early stages, external as adults	General stunting of plants, reduction in size of root system; causes disease known as "yellow dwarf" in Japan and China	Crop rotation; soil fumigation; planting of resistant varieties	32,57	13
Sedentary parasites, internal in early stages, becoming largely external as adults; attack roots, other underground parts	Stunting of plant, decrease in size of root system; often increase in number of small branch rootlets	Crop rotation; soil fumigation; planting of resistant varieties	12,38	14
Sedentary parasites of roots, other underground parts; internal in early stages, external as adults	Stunting of plant, overall decrease in size of root system; often increase in number of small branch rootlets	Crop rotation; soil fumigation with dichloropropene-dichloropropane mixture before planting (sugar beet)	19,27,42, 53	15
Vagrant internal or partly external parasites of roots	Lesions leading to complete destruction and sloughing off of cortex	Soil fumigation	33	16

best known species. Undoubtedly distribution is far wider than indicated. /2/ Species of nematodes within a given
only one or two crop plants. /3/ Feeding habits and particular tissues attacked vary with the species, host plant, and
from those caused by other organisms or by poor growing conditions; hence it is important in making a diagnosis to

continued

	Species (Common Name)	Geographic Distribution[1]	Host[3]
	(A)	(B)	(C)
17	*Meloidogyne* spp. (root-knot nematode)	Worldwide; most common in warm climates	Over 2,000 plants; hosts of individual species more restricted
18	*Paratylenchus* spp. (pin nematode)	N. America, Hawaii, British Isles, Netherlands, western Africa	Many plants, including alfalfa, cabbage, celery, cowpea, cucumber, fig tree, oats, okra, pineapple, radish, wheat
19	*Pratylenchus* spp. (lesion nematode)	Worldwide	Many plants, including alfalfa, corn, cotton, small grains, strawberry, tobacco, trees and shrubs
20	*Radopholus oryzae* (rice-root nematode)	Louisiana, Texas, Indonesia, Japan, rice-growing areas of southeastern Asia	Rice, various grasses, and related monocotyledonous plants
21	*R. similis* (burrowing nematode)	Florida, Louisiana, Jamaica, West Indies, Cen. America, Peru, Brazil, Hawaii, Philippines, Formosa, Indonesia, India	About 50 different plants, including avocado, banana, black pepper, canna, citrus, coffee, rice, sugarcane, tea
22	*Trichodorus* spp. (stubby root nematode)	Widespread; important in southeastern United States, southern California, Nicaragua, Tunisia	Many plants, including beet, cabbage, cauliflower, celery, chayote, corn, cotton, fig
23	*Tylenchorhynchus* spp. (stunt nematode)	Apparently widespread	Many plants, including azalea, cotton, oats, sugarcane, tobacco, wheat
24	*Tylenchulus semipenetrans* (citrus nematode)	Florida, Texas, California, most citrus fruit-growing regions; southern Europe	Most *Citrus* and closely related genera; olive
25	*Xiphinema* spp. (dagger nematode)	Worldwide	Many plants, shrubs, trees, including clove, corn, laurel oak, oats, pecan, rose, strawberry, some grasses

/1/ Information on geographic distribution of plant parasitic nematodes is fragmentary and incomplete, even for the genus vary in ability to attack plants; some have a rather wide host range, others are highly host-specific, attacking stage of development of the host and parasite. /4/ Symptoms of nematode damage are often difficult to distinguish find the nematode in the diseased tissue or soil adjacent to the roots of affected plants. /5/ All species in the genus wood and potato tubers, respectively.

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PARASITES: PLANTS

Feeding Habits[3] (D)	Symptoms[4] (E)	Control (F)	Reference (G)	
Sedentary endoparasites of roots, other underground parts	Swellings, galls, often local necrosis of tissues; increase or reduction of branch rootlets	Annual crops: rotation and fumigation; planting of resistant varieties; hot-water treatment of bulbs, corms, tubers	9,10,28	17
Vagrant ectoparasites of roots and other underground structures	Stunting of plants from root injury and retarded root growth	Fumigation somewhat effective	35,36,54	18
Vagrant endoparasites of roots and tubers[5]	Small brown root lesions; causes "brown root rot" of tobacco	Crop rotation, tobacco; row fumigation with dichloropropene-dichloropropane mixture	45	19
Vagrant endoparasites of roots	Root lesions, destruction of cortex, root hairs; in Indonesia associated with "mentek," a rice root rot	No established control measures	2,55,56	20
Vagrant endoparasites of roots	Root lesions and disintegration	Hot-water treatment of infected citrus nursery stock; pulling of affected trees, then soil fumigation	6-8,49	21
Vagrant ectoparasites of root tips	Devitalized root tips, causing numerous short, stubby branch rootlets	No satisfactory control known	17	22
Mostly external, occasionally internal vagrant parasites of roots	Stunting of plant	Soil fumigation	30,43	23
Females are sedentary, partly external parasites of roots	Extensive necrosis, discoloration of cortex of small roots	Planting of uninfected stock on clean land	3,51	24
Vagrant ectoparasites of root tips, sides of succulent roots	Devitalized root tips, necrosis of small roots, gall-like swellings, clusters of small stubby branches	Soil fumigation	14,44,54	25

best known species. Undoubtedly distribution is far wider than indicated. /2/ Species of nematodes within a given only one or two crop plants. /3/ Feeding habits and particular tissues attacked vary with the species, host plant, and from those caused by other organisms or by poor growing conditions; hence it is important in making a diagnosis to *Pratylenchus* are root parasites, with the exception of *P. mahogani* and *P. scribneri* observed in diseased mahogany

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132. VIRAL DISEASES: ANIMALS

Abbreviations: NP = nasopharyngeal; CNS = central nervous system; CSF = cerebrospinal fluid; RBC = red blood cells.

	Virus	Natural Host	Location in Natural Infection	Natural Transmission	Experimental Host	Tissue Culture (Growth in Egg[1])	Estimated Size[2] mμ	Remarks
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
1	Adenovirus	Man, cattle, chicken, dog, monkey, mouse	Respiratory and intestinal tracts	NP secretions	Man (?), dog (?), suckling hamster	Human tumor, monkey kidney, dog and chick embryo	85 (em)	Variable pathogenicity; may agglutinate RBC
2	Bluetongue	Cattle, sheep	Blood, all organs	*Culicoides* midge	Goat, hamster, suckling mouse	Sheep kidney (+)	100-150 (mf)	Several antigenic types
3	Chicken pox (varicella)	Man	Fluid and crusts of cutaneous lesions	Air-borne contact		Human foreskin and embryo	210-243 (em)	Antigenically identical to herpes zoster
4	Cowpox	Man, cattle	Cutaneous lesions on teat and udder	Contact with discharge from lesion, hands of milker	Rabbit, guinea pig	Cattle fetus, skin (+)		Antigenically related to vaccinia
5	Coxsackie	Man	Feces, blood, pharynx, saliva, CNS	Ingestion	Suckling mouse; hamster, monkey, chimpanzee	Newborn mouse; human, chick, monkey, and mouse embryo (+)	37 (em)	Thirty or more antigenic types
6	Dengue	Man, mosquito	Blood	*Aedes* mosquito	Mouse	Monkey kidney (+)	17-25 (mf)	Four antigenic types
7	Distemper, canine	Dog, ferret, other carnivores	Blood, secretions, excretions	Contact with secretions, excretions	Ferret, hamster, suckling mouse	Dog kidney (+)	20-22 (em)	Classical, neurotrophic, hard-pad types
8	Encephalitis, western equine	Man, horse, domestic and wild birds	CNS, blood, spleen	*Culex* mosquito	Mouse, many domestic and wild animals	Human and chick embryo, hamster and monkey kidney (+)	25 (mf); 40 (c, em)	Antigenically distinct; Arbor group A
9	Foot-and-mouth disease	Man, cattle, goat, sheep, swine	Blood, saliva, milk, urine	Contact with secretions, excretions; raw garbage	Rabbit, guinea pig, young dog, mouse, rat, chick	Guinea pig and cattle epithelium (+)	22 (em)	Three or more antigenic types; agglutinates RBC
10	Fowl plague	Domestic fowl, some wild birds	Blood, secretions, excretions	Ingestion	Starling, canary, mouse, rat, rabbit, ferret	Chick embryo (+)	60-140 (mf, c, em)	Antigenic variants; agglutinates RBC
11	Herpes simplex	Man	Skin, cornea, blood, mucosa, CNS	Contact ?	Rabbit, mouse	Rabbit and chick embryo (+)	100-150 (mf)	Antigenically related to pseudorabies, B-viruses
12	Hog cholera	Swine	Blood, all secretions, excretions	Contact with secretions, excretions, raw garbage	Rabbit, guinea pig	Swine marrow, testis, spleen, kidney, white blood cells	27 (em)	Antigenic, neurotrophic variants
13	Infectious hepatitis	Man	Blood, feces	Ingestion	Man ?	HeLa and other human cells ?	Passes Seitz	Two antigenic types
14	Influenza	Man	Respiratory tract	Contact with NP secretions	Ferret, mouse	Chick embryo (+)	80-120 (mf, c, em)	Antigenic types A-C; agglutinates RBC
15	Louping ill	Man, cattle, sheep	CNS, blood; CSF (man)	Tick; contact with infected animals (man)	Mouse, vole, swine, cattle, monkey	Chick embryo (+)	15-20 (mf); 22-27 (c)	Antigenically related to Russian Far East virus
16	Lymphogranuloma venereum	Man	Genital lesion, CSF, inguinal lymph node	Direct contact with lesion or exudate	Mouse, guinea pig, monkey	Chick and mouse embryo; guinea pig and mouse testis (+)	300 (dm); 438 (em)	Antigenically related to psittacosis; produces toxin

/1/ Growth in embryonated chicken egg indicated by plus sign in parentheses. /2/ Method of determination given in parentheses: (c) = centrifugation; (dm) = direct microscopy; (em) = electron microscopy; (mf) = membrane filtration.

continued

132. VIRAL DISEASES: ANIMALS

	Virus	Natural Host	Location in Natural Infection	Natural Transmission	Experimental Host	Tissue Culture (Growth in Egg[1])	Estimated Size[2] mμ	Remarks
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
17	Measles (rubeola)	Man	Blood, skin, respiratory tract, urine	Contact with NP secretions	Monkey	Chick embryo, human and monkey kidney (+)	120-150 (em)	
18	Measles, German (rubella)	Man	Respiratory tract, blood, urine	Contact with NP secretions	Man ?	Human amnion, monkey kidney	<800 (mf)	May produce fetal malformation
19	Molluscum contagiosum	Man	Skin	Direct contact		HeLa cells	190-250 (em)	
20	Mumps	Man	Salivary glands, blood, gonads, CSF	Droplets of saliva	Monkey, hamster	Chick and mouse embryo (+)	90-135 (mf); 140-268 (em)	Agglutinates RBC; produces hemolysin
21	Newcastle disease	Man, cattle, domestic fowl, some wild birds	Conjunctival and nasal secretions (man); lungs (calf); blood, secretions, excretions (ovipara)	Contact with secretions, excretions, sick animals; raw garbage (poultry scraps)	Common laboratory animals, cattle, quail, sparrow	Chick embryo, chicken trachea cells, swine embryo lymph node (+)	70-180 (em)	Neural pneumonic visceral strains; agglutinates RBC
22	Parainfluenza	Man, cattle	Respiratory tract	Contact with NP secretion		Monkey and cattle kidney	80-150 (em)	Four or more antigenic types
23	Poliomyelitis	Man	CNS, intestinal tract, blood	Ingestion	Chimpanzee, monkey, hamster, mouse	Human, monkey	28 (em)	Three antigenic types
24	Polyoma	Mouse	Blood, tissues, excretions	Contact	Suckling mouse, hamster, and rat	Mouse embryo	45 (em)	Tumorigenic for newborn mice; agglutinates RBC
25	Psittacosis	Man, psittacine birds, duck, chicken	Lung, spleen, liver, sputum (man); respiratory secretions, cloacal contents	Inhalation of dried secretions, droppings, contact with infected tissues	Mouse, guinea pig, monkey	Chick embryo, mouse (+)	455 (em)	Produces toxin
26	Rabies	All mammals	CNS, salivary and lacrimal glands, kidney, pancreas, saliva	Through broken epithelium contaminated with saliva	Mammals, domestic fowl	Rabbit, rat, mouse, chick embryo (+)	100-150 (mf)	
27	Reovirus	Man, cattle, monkey, mouse	Intestinal tract	Ingestion ?	Man ?	Human, monkey	60-90 (em)	Three antigenic types; agglutinates RBC
28	Rift Valley fever	Man, sheep	Blood, liver	Mosquito ?	Cattle, goat, monkey, mouse	Chick embryo (+)	23-35 (mf)	
29	Rinderpest	Domestic animals, deer	Blood, secretions, excretions	Ingestion	Rabbit, guinea pig, Chinese pig	Chick embryo (+)	Passes V Berkefeld	
30	Rous sarcoma	Chicken	Tumor, blood	Contact, egg	Chick, turkey	Chick embryo (+)	65-90 (em)	One of several related tumorigenic chicken viruses
31	Shope papilloma	Rabbit	Skin		Domestic rabbit, hamster		22-35 (mf); 32-50 (c)	Malignancy becomes carcinomatous
32	Silkworm jaundice	*Bombyx mori*	Fat, hypodermis, blood cells; other tissues ?	Oral; egg ?	Gypsy moth (?), nun moth ?		40-288 (em)	Inclusion bodies: polyhedral

/1/ Growth in embryonated chicken egg indicated by plus sign in parentheses. /2/ Method of determination given in parentheses: (c) = centrifugation; (dm) = direct microscopy; (em) = electron microscopy; (mf) = membrane filtration.

continued

132. VIRAL DISEASES: ANIMALS

	Virus	Natural Host	Location in Natural Infection	Natural Transmission	Experimental Host	Tissue Culture (Growth in Egg[1])	Estimated Size[2] mμ	Remarks
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
33	Smallpox (variola)	Man; monkey ?	Cutaneous lesions, NP secretions, mucosa, blood	Inhalation of secretions, scabs	Monkey, rabbit	Human embryo, skin, kidney, tumor, etc. (+)	244-302 (em)	Antigenically related to vaccinia; agglutinates RBC
34	Trachoma	Man	Conjunctiva, conjunctival exudate	Contact with conjunctival exudate	Ape; man ?	(+)	250 (dm)	
35	Vaccinia	Man (?), rabbit (?), cattle ?	Cutaneous lesions ?		Man, cattle, monkey, rabbit, mouse	Rabbit, chicken; guinea pig adult and embryo (+)	236-252 (mf)	Antigenically related to smallpox; agglutinates RBC
36	Wart (verruca)	Man	Cutaneous lesions	Contact ?	Man ?		Passes N Berkefeld	
37	Yellow fever	Man, monkey	Blood, liver, CNS, spleen, lymph nodes	*Aedes aegypti* and other culicines	Mouse, monkey, hedgehog	Chick and mouse embryo (+)	12-19 (c); 22 (mf)	Arbor group B

/1/ Growth in embryonated chicken egg indicated by plus sign in parentheses. /2/ Method of determination given in parentheses: (c) = centrifugation; (dm) = direct microscopy; (em) = electron microscopy; (mf) = membrane filtration.

Contributors: (a) Thompson, Randall L., (b) Moses, Harold E., (c) Minton, Sherman A., Jr.

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133. VIRAL DISEASES: PLANTS

	Host Plant and Disease	Distribution	Principal Insect Vector	Other Means of Transmission	Symptoms
	(A)	(B)	(C)	(D)	(E)
	Allium cepa (garden onion)				
1	Onion yellow dwarf	United States, Germany, New Zealand, USSR	Aphids (including *Aphis maidis, A. rumicis*)	Leaf rubbing	Leaves yellowed, crinkled; plants dwarfed; bulbs small; few seeds
	Beta vulgaris (beet)				
2	Beet yellows	Belgium, Netherlands, Denmark, England	Aphids (including *Aphis fabae, Myzus persicae*)	....	Leaves yellow, thick, brittle; necrosis in secondary phloem
3	Sugar beet curly top	Western North America	Leafhopper *(Circulifer tenellus)*	Grafting; dodder	Leaves curled, enations on veins; plant stunted; many rootlets

continued

133. VIRAL DISEASES: PLANTS

	Host Plant and Disease	Distribution	Principal Insect Vector	Other Means of Transmission	Symptoms
	(A)	(B)	(C)	(D)	(E)
	Cucumis sativus (cucumber)				
4	Cucumber mosaic	Almost worldwide	Aphids (including *Aphis gossypii, Myzus persicae*)	Leaf rubbing; dodder	Leaves mottled, distorted, small; plant stunted; fruits mottled
5	Cucurbit mosaic	England	....	Leaf rubbing	Chlorotic mottling and distortion of foliage; plant stunted
	Fragaria hybrida (strawberry)				
6	Strawberry stunt	United States	Aphid (*Capitophorus fragaefolii*)	Grafting	Leaves green, luster dull; leaflets cupped; plant stunted; fruits small
	Gossypium hirsutum (upland cotton)				
7	Cotton leaf curl	Sudan, Nigeria	Whitefly (*Bemisia gossypiperda*)	Grafting	Leaves pale-spotted, puckered, unsymmetrical; internodes shortened
	Lactuca sativa (lettuce)				
8	Lettuce mosaic	Worldwide	Aphids (*Macrosiphum gei, Myzus persicae*)	Leaf abrasion; seeds	Clearing of veins, followed by systemic chlorotic mottling
	Lycoperiscon esculentum (tomato)				
9	Tomato bushy stunt	British Isles	....	Leaf rubbing; dodder	Foliage yellowed; plant stunted; axillary buds stimulated
10	Tomato spotted wilt	Almost worldwide	*Frankliniella moultoni, F. schultzei, Thrips tabaci*	Leaf abrasion	Bronze-ring lesions, necrosis or mottling; fruit discolored
	Medicago sativa (alfalfa)				
11	Alfalfa mosaic	United States	Aphids (*Macrosiphum pisi, M. solanifolii*)	Leaf rubbing	Systemic chlorotic mottling, often masked
	Nicotiana tabacum (common tobacco)				
12	Tobacco etch	United States	Aphids (especially *Myzus persicae*)	Leaf rubbing	Systemic chlorotic mottling with traces of whitish etching
13	Tobacco leaf curl	Africa, India, Sumatra, Formosa	Whitefly (*Bemisia gossypiperda*)	Grafting	Leaves curled, wrinkled; veins thick, enations; plant stunted
14	Tobacco mosaic	Worldwide	....	Leaf rubbing; dodder; soil	Systemic chlorotic mottling; some distortion of leaves
15	Tobacco necrosis	United States, British Isles, Australia	....	Leaf rubbing; soil; fungus vector (*Olpidium* spp.)	Necrosis in midrib and veins of lower leaves in winter
16	Tobacco ring spot	United States	....	Leaf rubbing; seeds; nematode vector (*Xiphinema americanum*)	Necrotic, ringlike primary and secondary lesions; later recovery
	Oryza sativa (rice)				
17	Rice dwarf	Japan, Philippine Islands	Leafhoppers (including *Nephotettix apicalis*)	....	Leaves chlorotic, spotted, streaked; internodes and roots short
	Phaseolus vulgaris (kidney bean)				
18	Bean mosaic	Almost worldwide	Aphids (including *Aphis rumicis*)	Leaf abrasion; seeds	Systemic chlorotic mottling
19	Southern bean mosaic	Southern United States	....	Leaf rubbing; seeds	Mottling in some varieties, localized or systemic necrosis in others

continued

133. VIRAL DISEASES: PLANTS

	Host Plant and Disease	Distribution	Principal Insect Vector	Other Means of Transmission	Symptoms
	(A)	(B)	(C)	(D)	(E)
	Prunus persica (peach)				
20	Peach phony disease	Southeastern United States	Leafhoppers (including *Homalodisca triquetra*)	Root grafting	Foliage abnormally green; tree dwarfed, fruit small
21	Peach rosette	United States	....	Budding; dodder	Stems short with dwarfed leaves; veins thickened; tree dies soon
22	Peach X-disease	United States	Leafhoppers (including *Colladonus clitellarius*)	Budding	Leaves light green, tattered; old leaves drop; fruit bitter
23	Peach yellows	Eastern United States, eastern Canada	Leafhopper (*Macropsis trimaculata*)	Budding	Leaves chlorotic; shoots erect, thin, numerous; tree dies soon
	Solanum tuberosum (potato)				
24	Potato aucuba mosaic	United States, Europe	Probably aphid (*Myzus persicae*)	Leaf rubbing	Yellow mottling of foliage; some necrosis in tubers
25	Potato leaf roll	Wherever potatoes are grown	Aphids (especially *Myzus persicae*)	Grafting	Leaves thick, leathery, rolled, starchy; plant small; few tubers
26	Potato mild mosaic	United States, England, Holland	Aphids (*Aphis abbreviata*, *Myzus persicae*)	Leaf rubbing	Mild chlorotic mottling or masked symptoms in most varieties
27	Potato mottle	Worldwide	....	Leaf rubbing; root and leaf contacts	No obvious disease, or very mild chlorotic mottling
28	Potato spindle tuber	United States, Canada	Aphids (*Macrosiphum solanifolii*, *Myzus persicae*)	Leaf rubbing; seed-piece cutting	Leaves small, erect, dark green; plant brittle; tubers tapered
29	Potato veinbanding	United States, Brazil, England, France	Aphids (especially *Myzus persicae*)	Leaf rubbing	Chlorotic mottling, necrotic stemstreak, or no obvious disease
30	Potato witches'-broom	United States, USSR	....	Tuber core graft, stem graft	Leaves small, pale; branches numerous, spindly; tubers small
31	Potato yellow dwarf	United States, Canada	Leafhopper (*Aceratagallia sanguinolenta*)	Leaf abrasion in some hosts; grafting	Leaves yellowed, plant dwarfed; tubers few, small, often cracked
	Trifolium incarnatum (crimson clover)				
32	Clover club leaf	United States (New Jersey)	Leafhopper (*Agalliopsis novella*)	....	Plant dwarfed; leaves small, yellowed or reddened at margins
33	Wound tumor	United States	Leafhoppers (*Agallia constricta*, *Agalliopsis novella*)	....	Experimentally: veins thickened, enations; plant dwarfed
	Triticum aestivum (wheat)				
34	Wheat mosaic	United States, Japan	....	Leaf abrasion; soil	Systemic chlorotic mottling; dwarfing; vacuolate inclusions
35	Wheat streak mosaic	United States, Canada	Mite (*Aceria tulipae*)	Leaf abrasion	Systemic chlorotic mottling, streaking of leaves
36	Winter-wheat mosaic	USSR	Leafhopper (*Deltocephalus striatus*)	....	Chlorotic mottling; phloem necrosis, vacuolate inclusions
	Zea mays (corn)				
37	Maize streak	Africa	Leafhoppers (*Cicadulina mbila*, *C. storeyi*, *C. zeae*)	....	Chlorotic spotting, streaking of leaves

Contributor: Holmes, Francis O.

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134. RICKETTSIAL PARASITES: MAMMALS AND BIRDS

Host (column B): Animals are listed in order of decreasing susceptibility.

	Species	Host	Disease or Disorder	Method of Transmission
	(A)	(B)	(C)	(D)
1	*Anaplasma centrale*	Cattle	Benign anaplasmosis	Tick to host
2	*A. marginale*	Cattle	Malignant anaplasmosis	Tick to host
3	*A. ovis*	Sheep, goat	Ovine anaplasmosis	Tick to host
4	*Bartonella bacilliformis*	Man	Oroya fever	Sand fly to man
5	*Chlamydia oculogenitalis*	Man	Inclusion blennorrhea, inclusion conjunctivitis, neonatal conjunctivitis	Contact; contaminated swimming pools
6	*C. trachomatis*	Man, ape, monkey	Trachoma	Contact
7	*Colesiota conjunctivae*	Sheep, cattle, goat	Ophthalmia	Uncertain
8	*Colletsia pecoris*	Cattle, sheep, goat	Conjunctivitis ?	Uncertain
9	*Cowdria ruminantium*	Goat, sheep, cattle	Heartwater	Tick feces; tick to host
10	*Coxiella burneti*	Man, cattle, sheep, goat	Q fever	Tick feces; host to tick to host; contact with domestic animals; inhalation of infected dust; contaminated milk
11	*Ehrlichia bovis*	Cattle	Bovine rickettsiosis	Tick to host
12	*E. canis*	Dog	Canine rickettsiosis	Tick to host
13	*E. ovina*	Sheep	Ovine rickettsiosis	Presumed tick to host
14	*E. phagocytophila*	Sheep	Ovine rickettsiosis	Tick to host
15	*Eperythrozoon* spp.	Cattle, mouse, sheep, swine	Eperythrozoonosis, anemia	Mouse louse to mouse (other arthropods suspected)
16	*Grahamella talpae*	Mole	Grahamellosis, anemia	Uncertain
17	*Haemobartonella* spp.	Animals	Haemobartonellosis, anemia	Flea to host
18	*Miyagawanella bronchopneumoniae*	Mouse	Mouse pneumonitis	Contact
19	*M. felis*	Cat	Feline pneumonitis	Contact
20	*M. lymphogranulomatosis*	Man	Lymphogranuloma venereum (lymphogranuloma inguinale)	Venereal contact
21	*M. ornithosis*	Man, nonpsittacine birds	Ornithosis	Inhalation of infected dust; bird to man, man to man
22	*M. psittaci*	Man, psittacine birds	Psittacosis	Inhalation of infected dust; bird to man, man to man
23	*Neorickettsia helminthoeca*	Dog, fox, coyote	Salmon poisoning	Intestinal parasitic fluke to dog
24	*Rickettsia akari*	Man	Rickettsial pox	Mite to man
25	*R. conorii*	Man; dog as reservoir	Boutonneuse (Marseilles, Mediterranean) fever	Tick to man
26	*R. prowazekii*	Man	Epidemic (classic Old World) typhus	Louse feces; man to louse to man
27	*R. rickettsii*	Man, rabbit, squirrel	Rocky Mountain spotted fever	Tick to man
28	*R. siberica*	Man, rodents	Siberian tick typhus	Tick to host
29	*R. tsutsugamushi*	Man, monkey, rodents	Tsutsugamushi fever (scrub typhus)	Mite to man
30	*R. typhi*	Man, rodents	Murine or endemic typhus	Flea feces; rat to flea to man
31	*Ricolesia bovis*	Cattle	Infectious conjunctivitis	Contact
32	*R. caprae*	Goat	Infectious conjunctivitis	Possibly contact
33	*R. conjunctivae*	Fowl	One form of ocular roup	Possibly contact
34	*R. lestoquardii*	Swine	Infectious conjunctivitis	Possibly contact
35	*Rochalimaea quintana*	Man	Trench fever	Body louse to man

Contributor: Philip, Cornelius B.

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134. RICKETTSIAL PARASITES: MAMMALS AND BIRDS

References: [1] Breed, R. S., E. G. D. Murray, and N. R. Smith, ed. 1957. Bergey's Manual of determinative bacteriology. Ed. 7. Williams and Wilkins, Baltimore. [2] Burrows, W. 1963. Textbook of microbiology. Ed. 18. W. B. Saunders, Philadelphia. [3] Hagan, W. A., and D. W. Bruner. 1961. The infectious diseases of domestic animals. Ed. 4. Comstock, Ithaca. [4] Hull, T. G. 1955. Diseases transmitted from animals to man. Ed. 4. C. C. Thomas, Springfield, Ill. [5] Merchant, I. A., and R. A. Packer. 1961. Veterinary bacteriology and virology. Ed. 6. Iowa State Univ. Press, Ames. [6] Moulton, F. R., ed. 1948. Rickettsial diseases of man. Symposium. American Association for the Advancement of Science, Washington, D. C. [7] Philip, C. B. 1950. In R. L. Pullen, ed. Communicable diseases. Lea and Febiger, Philadelphia. p. 781. [8] Rivers, T. M., and F. L. Horsfall, Jr., ed. 1959. Viral and rickettsial infections of man. Ed. 3. J. B. Lippincott, Philadelphia.

135. BACTERIAL PARASITES: MAMMALS AND BIRDS

Host (column B): Animals are listed in order of decreasing susceptibility.

	Species (A)	Host (B)	Disease or Disorder (C)	Method of Transmission (D)
1	*Actinobacillus lignieresii*	Cattle, swine	Actinobacillosis (wooden tongue)	Not definitely known
2	*A. mallei*	Horse, man	Glanders	Contact; contaminated feed, water
3	*Actinomyces bovis*	Cattle, swine, horse, man	Actinomycosis (lumpy jaw)	Buccal cavity; transmission not definitely known
4	*Bacillus anthracis*	Man	Anthrax	Soil-borne; contact with infected animal by-products, carcasses
5		Cattle, sheep, horse, mule, swine	Anthrax (splenic fever)	Soil-borne; infected feed, water, carcasses
6	*Bordetella pertussis*	Man	Whooping cough	Flora of respiratory tract; droplet infection
7	*Borrelia anserina*	Fowl	Spirochetosis	Arthropod vector; feces-borne
8	*B. recurrentis*	Man	European relapsing fever	Arthropod vector
9	*B. theileri*	Cattle	Spirochetosis	Arthropod vector
10	*B. vincentii*	Man	Associated with *Fusobacterium fusiforme* in Vincent's angina	Buccal cavity; transmission not definitely known
11	*Brucella abortus*	Cattle, man	Brucellosis (undulant fever)	Ingestion of infected milk; contact
12	*B. melitensis*	Goat, sheep, man	Brucellosis (undulant fever)	Ingestion of infected milk; contact
13	*B. suis*	Swine, man	Brucellosis (undulant fever)	Contact
14	*Clostridium botulinum*	Man, chicken, duck, horse, mule, cattle	Botulism, food intoxication, limberneck of fowl	Ingestion of toxin in food
15	*C. chauvoei*	Cattle, man	Blackleg, symptomatic anthrax	Soil-borne; wound infection
16	*C. haemolyticum*	Cattle, sheep	Icterohemoglobinuria	Soil-borne; contaminated feed, water
17	*C. novyi*	Sheep, man	Infectious necrotic hepatitis	Soil-borne; associated with liver fluke infection
18	*C. perfringens*	Man	Gas gangrene	Soil-borne; wound infection
19		Sheep	Dysentery in lamb, infectious enterotoxemia	Soil-borne; wound infection
20	*C. septicum*	Horse, sheep, cattle, man	Malignant edema	Soil-borne; wound infection
21	*C. tetani*	Man, sheep, cattle, goat, swine, horse	Tetanus (lockjaw)	Soil-borne; wound infection
22	*Corynebacterium diphtheriae*	Man	Diphtheria	Carrier contact
23	*C. equi*	Horse	Pneumonia of foal	Possible in utero
24		Swine	Submaxillary gland infection	Contaminated soil, feed
25	*C. pseudotuberculosis*	Sheep, goat	Caseous lymphadenitis	Contaminated feed, water
26		Horse, deer, elk, moose, mountain sheep	Ulcerative lymphangitis (pseudoglanders)	Contact; wound infection
27	*C. pyogenes*	Cattle, swine, sheep, goat, deer	Mastitis, purulent infections, arthritis	Inhabits mucous membranes; contact; wound infection

continued

135. BACTERIAL PARASITES: MAMMALS AND BIRDS

	Species (A)	Host (B)	Disease or Disorder (C)	Method of Transmission (D)
28	*Corynebacterium renale*	Cattle, swine	Pyelonephritis	Inhabits mucous membranes; transmission not definitely known
29	*Diplococcus pneumoniae*	Man	Lobar pneumonia, meningitis, endocarditis	Carrier contact
30	*Erysipelothrix insidiosa*	Man	Erysipeloid	Wound infection; contact with infected carcasses
31		Swine, sheep, fowl	Erysipelas	Feces-borne; contaminated soil, feed, water
32	*Escherichia coli*	Man, domestic animals	Genitourinary and intestinal infections	Feces-borne; normal flora of intestinal tract.
33	*Fusobacterium fusiforme*	Man	Associated with ulcerative stomatitis (Vincent's angina)	Buccal cavity; transmission not definitely known
34	*Haemophilus ducreyi*	Man	Soft chancre, chancroid	Direct genital contact
35	*H. gallinarum*	Chicken	Infectious coryza	Contact
36	*H. haemoglobinophilus*	Dog	Prepucial infection	Direct sexual contact
37	*H. influenzae*	Man	Meningitis, obstructive respiratory infections	Flora of respiratory tract; droplet infection
38	*H. suis*	Swine	Associated with viral influenza	Contact; flora of respiratory tract
39	*Klebsiella pneumoniae*	Man, horse, cattle	Respiratory infection; mastitis (cattle)	Contact; flora of respiratory tract
40	*Leptospira canicola*	Dog, man, swine, cattle	Leptospirosis (Stuttgart's disease of dog)	Direct contact; contamination of water by infected urine
41	*L. icterohaemorrhagiae*	Man, dog, swine, cattle, rodents	Leptospirosis (Weil's disease)	Direct contact; contamination of water by infected urine
42	*L. pomona*	Cattle, swine, man	Leptospirosis (swineherd's disease)	Direct contact; contamination of water by infected urine
43	*Listeria monocytogenes*	Man, domestic animals, fowl	Listeriosis, meningoencephalitis, abortion	Not definitely known
44	*Moraxella bovis*	Cattle	Infectious keratitis	Contact
45	*M. lacunata*	Man	Conjunctivitis	Not definitely known
46	*Mycobacterium avium*	Fowl, swine	Tuberculosis	Contact; feces-borne; contaminated feed, water
47	*M. bovis*	Cattle, man, swine	Tuberculosis	Contact; feces-borne; contaminated feed, water, milk
48	*M. leprae*	Man	Hansen's disease (leprosy)	Not definitely known
49	*M. paratuberculosis*	Cattle, sheep	Johne's disease	Contact; feces-borne; contaminated feed, water
50	*M. tuberculosis*	Man	Tuberculosis	Contact; via respiratory or alimentary tract
51	*Neisseria catarrhalis*	Man	Catarrhal inflammations	Flora of respiratory tract
52	*N. gonorrhoeae*	Man	Gonorrhea	Direct sexual contact
53	*N. meningitidis*	Man	Epidemic cerebrospinal meningitis	Infection from respiratory tract of carrier
54	*Pasteurella multocida*	Domestic animals, fowl, man	Hemorrhagic septicemia, bronchiectasis, conjunctivitis	Contact; contaminated feed, water; bites
55	*P. pestis*	Man, rodents	Bubonic and pneumonic plague	Flea bite from infected rat; droplet infection
56	*P. pseudotuberculosis*	Guinea pig, rabbit, borse, cattle, goat, rodents, dog, cat, monkey, fowl	Pseudotuberculosis	Soil-borne; contaminated water, fodder, milk
57	*P. tularensis*	Man, rodents, lagomorphs	Tularemia	Contact with contaminated carcasses; insect vector
58	*Proteus vulgaris*	Man	Genitourinary and intestinal infections	Feces-borne
59	*Pseudomonas aeruginosa*	Man, animals	Suppurative processes, septicemia, meningitis, genitourinary infections	Contaminated water, soil, feces; wound infection
60	*Salmonella enteritidis*	Man, rodents	Food poisoning, gastroenteritis	Feces-borne
61	*S. gallinarum*	Fowl	Fowl typhoid, bacillary white diarrhea	Feces-borne; ovarian transmission
62	*S. hirschfeldii*	Man	Paratyphoid fever	Feces-borne
63	*S. paratyphi A*	Man	Paratyphoid fever	Feces-borne
64	*S. paratyphi B*	Man	Paratyphoid fever	Feces-borne
65	*S. typhimurium*[1]	Man, rodents	Food poisoning, gastroenteritis	Feces-borne

/1/ A natural pathogen for all warm-blooded animals

continued

135. BACTERIAL PARASITES: MAMMALS AND BIRDS

	Species	Host	Disease or Disorder	Method of Transmission
	(A)	(B)	(C)	(D)
66	*Salmonella typhosa*	Man	Typhoid fever	Feces-borne
67	*Shigella dysenteriae*	Man	Dysentery	Feces-borne; contaminated food, water
68	*S. equirulis*	Horse	Joint infection, nephritis	Possible in utero
69	*Sphaerophorus necrophorus*	Man ?	Associated with ulcerative colitis ?	Feces-borne; associated with unsanitary conditions
70		Horse	Gangrenous dermatitis (scratches)	Feces-borne; associated with unsanitary conditions
71		Cattle	Calf diphtheria	Feces-borne; associated with unsanitary conditions
72		Sheep, goat	Lip-and-leg ulceration, ulcerative stomatitis, foot rot	Feces-borne; associated with unsanitary conditions
73		Swine	Ulcerative stomatitis, enteritis	Feces-borne; associated with unsanitary conditions
74	*Spirillum minus*	Man, rodents	Rat-bite fever	Rat bite
75	*Staphylococcus aureus*	Man, animals	Suppurative processes, food poisoning, septicemia	Wound infection; contaminated food; flora of skin and mucous membranes
76	*Streptococcus agalactiae*	Cattle	Mastitis	Contaminated milking equipment
77	*S. dysgalactiae*	Cattle	Mastitis	Contaminated milking equipment
78	*S. equi*	Horse	Strangles	Contact; contaminated water, feed
79	*S. pyogenes*	Man, vole	Scarlet fever, septic sore throat	Direct personal contact; contaminated milk
80	*S. uberis*	Cattle	Mastitis	Contaminated milking equipment
81	*Treponema pallidum*	Man	Syphilis	Direct sexual contact
82	*Vibrio comma*	Man	Cholera	Feces-borne from carrier; contaminated food, water
83	*V. fetus*	Cattle, sheep	Vibrionic abortion, sterility	Direct sexual contact
84	*V. jejuni*	Cattle	Dysentery	Feces-borne; contaminated feed and water

Contributor: Cunningham, Charles H.

References: [1] Breed, R. S., E. G. D. Murray, and N. R. Smith, ed. 1957. Bergey's Manual of determinative bacteriology. Ed. 7. Williams and Wilkins, Baltimore. [2] Burrows, W. 1963. Textbook of microbiology. Ed. 18. W. B. Saunders, Philadelphia. [3] Dubos, R. J. 1958. Bacterial and mycotic infections of man. Ed. 3. J. B. Lippincott, Philadelphia. [4] Hagan, W. A., and D. W. Bruner. 1961. The infectious diseases of domestic animals. Ed. 4. Comstock, Ithaca. [5] Hull, T. G. 1955. Diseases transmitted from animals to man. Ed. 4. C. C. Thomas, Springfield, Ill. [6] Merchant, I. A., and R. A. Packer. 1961. Veterinary bacteriology and virology. Ed. 6. Iowa State Univ. Press, Ames.

136. BACTERIAL PARASITES: PLANTS

	Host Plant and Pathogen	Disease
	(A)	(B)
	Acer spp. (maple)	
1	*Pseudomonas aceris*	Leaf spot
2	*Xanthomonas acernea*	Leaf blight
	Allium cepa (garden onion)	
3	*Pseudomonas alliicola*	Scale rot
4	*P. cepacia*	Sour skin
5	*P. cichorii, P. marginalis*	Soft rot
6	*Xanthomonas striaformans*	Stripe
	Antirrhinum majus (snapdragon)	
7	*Xanthomonas antirrhini*	Leaf spot
	Avena sativa (common oat)	
8	*Pseudomonas coronafaciens*	Halo blight
9	*P. coronafaciens atropurpurea*	Purple spot
10	*P. striafaciens*	Stripe blight
11	*Xanthomonas translucens*	Blight
	Beta vulgaris (common beet)	
12	*Corynebacterium betae*	Silvering disease
	Beta vulgaris (common beet)	
13	*Erwinia scabiegena*	Blister scab
14	*Pseudomonas aptata*	Blight
15	*P. wieringae*	Ring rot
16	*Xanthomonas beticola*	Bacterial pocket
	Capsicum frutescens (bush red pepper)	
17	*Erwinia carotovora*	Soft rot
18	*Pseudomonas solanacearum*	Wilt
19	*Xanthomonas vesicatoria*	Bacterial spot
	Chrysanthemum spp. (chrysanthemum)	
20	*Erwinia chrysanthemi*	Bacterial blight
21	*Pseudomonas cichorii*	Leaf spot
	Citrus spp. (citrus)	
22	*Erwinia citrimaculans*	Fruit spot
23	*Pseudomonas syringae*	Blast and black pit
24	*Xanthomonas citri*	Canker

continued

136. BACTERIAL PARASITES: PLANTS

	Host Plant and Pathogen	Disease
	(A)	(B)
	Cucumis sativus (cucumber)	
25	*Erwinia tracheiphila*	Wilt
26	*Pseudomonas lachrymans*	Angular leaf spot
27	*Xanthomonas cucurbitae*	Leaf spot
	Cucurbita pepo (pumpkin)	
28	*Erwinia tracheiphila*	Wilt
	Daucus carota (carrot)	
29	*Erwinia carotovora*	Soft rot
30	*Xanthomonas carotae*	Leaf blight
	Fragaria virginiana (Virginia strawberry)	
31	*Corynebacterium fascians*	Cauliflower disease
32	*Xanthomonas fragariae*	Angular leaf spot
	Fraxinus spp. (ash)	
33	*Pseudomonas savastanoi fraxini*	Canker
	Gladiolus spp. (gladiolus)	
34	*Pseudomonas gladioli*	Rot
35	*P. marginata*	Corm scab and leaf blight
36	*Xanthomonas gummisudans*	Blight
	Glycine soja (soybean)	
37	*Pseudomonas glycinea*	Blight
38	*P. tabaci*	Wildfire
39	*Xanthomonas phaseoli sojensis*	Pustule
	Gossypium spp. (cotton)	
40	*Xanthomonas malvacearum*	Angular leaf spot
	Helianthus annuus (sunflower)	
41	*Pseudomonas helianthi*	Leaf spot
	Hordeum vulgare (barley)	
42	*Pseudomonas coronafaciens*	Halo blight
43	*P. striafaciens*	Stripe blight
44	*Xanthomonas translucens*	Blight
	Ipomea batatas (sweet potato)	
45	*Pseudomonas viciae*	Leaf and stem spot
46	*Streptomyces ipomoea*	Soil rot
	Iris spp. (iris)	
47	*Pseudomonas cichorii*	Leaf blight
48	*P. iridicola*	Leaf blight
49	*P. marginata*	Corm scab and leaf blight
50	*Xanthomonas tardicrescens*	Leaf blight
	Juglans spp. (walnut)	
51	*Erwinia nigrifluens*	Bark canker
52	*Xanthomonas juglandis*	Blight
	Lactuca sativa (lettuce)	
53	*Pseudomonas cichorii*	Head rot
54	*P. marginalis*	Marginal blight & rot
55	*P. viridilivida*	Leaf spot and wilt
56	*Xanthomonas vitians*	Wilt and rot
	Lycopersicon esculentum (tomato)	
57	*Corynebacterium michiganense*	Canker
58	*Pseudomonas gardeneri*	Fruit spot and scab
59	*P. solanacearum*	Wilt
60	*P. tomato*	Bacterial speck
61	*Xanthomonas vesicatoria*	Bacterial spot
	Malus pumila (common apple)	
62	*Agrobacterium rhizogenes*	Hairy root
63	*A. tumefaciens*	Crown gall
64	*Erwinia amylovora*	Fire blight
65	*Pseudomonas melophthora*	Brown rot of fruit
66	*P. papulans*	Blister spot
67	*P. pomi*	Fruit rot
68	*P. syringae*	Twig blight
	Medicago sativa (alfalfa)	
69	*Corynebacterium insidiosum*	Wilt
	Medicago sativa (alfalfa)	
70	*Pseudomonas medicaginis*	Stem blight
71	*Xanthomonas alfalfae*	Leaf spot
	Nicotiana spp. (tobacco)	
72	*Erwinia aroideae*	Hollow stalk and barn rot
73	*Pseudomonas angulata*	Angular leaf spot
74	*P. mellea*	Rust
75	*P. polycolor*	Leaf spot and wet rot
76	*P. pseudozoogloeae*	Black rust
77	*P. solanacearum*	Granville disease
78	*P. tabaci*	Wildfire
79	*Xanthomonas heterocea*	Rust
	Oryza sativa (rice)	
80	*Pseudomonas oryzicola*	Leaf spot
81	*P. setariae*	Stripe
82	*Xanthomonas oryzae*	Blight
83	*X. oryzicola*	Leaf streak
	Pastinaca sativa (parsnip)	
84	*Pseudomonas pastinacae*	Brown rot
	Phaseolus vulgaris (kidney bean)	
85	*Corynebacterium flaccumfaciens*	Wilt
86	*Pseudomonas flectens*	Pod twist
87	*P. phaseolicola*	Halo blight
88	*P. stizolobii*	Leaf spot
89	*P. syringae*	Lilac blight
90	*P. viridiflava*	Leaf spot and blight
91	*Xanthomonas phaseoli*	Common blight
92	*X. phaseoli fuscans*	Fuscous blight
	Phleum pratense (timothy)	
93	*Xanthomonas translucens phleipratensis*	Streak
	Pisum sativum (garden pea)	
94	*Pseudomonas pisi*	Blight
95	*Xanthomonas pisi*	Stem rot
	Populus spp. (poplar)	
96	*Corynebacterium humiferum*	Wetwood
97	*Pseudomonas rimaefaciens*	Canker
	Prunus domestica (garden plum)	
98	*Pseudomonas morsprunorum*	Canker and leaf spot
99	*P. syringae*	Canker and gummosis
100	*Xanthomonas pruni*	Fruit and leaf spot
	Prunus persica (peach)	
101	*Pseudomonas syringae*	Canker and gummosis
102	*Xanthomonas pruni*	Leaf and fruit spot
	Pyrus communis (pear)	
103	*Erwinia amylovora*	Fire blight
104	*Pseudomonas barkeri*	Blossom blight
105	*P. nectarophila*	Blossom blight
106	*P. syringae*	Twig and blossom blight
	Raphanus sativus (garden radish)	
107	*Pseudomonas maculicola*	Black spot
108	*Xanthomonas campestris*	Black rot
109	*X. vesicatoria raphani*	Leaf spot
	Rheum rhaponticum (garden rhubarb)	
110	*Erwinia rhapontici*	Crown rot
111	*Pseudomonas marginalis*	Soft rot
	Ribes aureum (golden currant)	
112	*Pseudomonas ribicola*	Leaf spot
	Rosa multiflora (Japanese rose)	
113	*Agrobacterium rhizogenes*	Hairy root

continued

136. BACTERIAL PARASITES: PLANTS

	Host Plant and Pathogen (A)	Disease (B)
	Rosa multiflora (Japanese rose)	
114	*Agrobacterium tumefaciens*	Crown gall
115	*Pseudomonas syringae*	Leaf spot and blast
	Salix spp. (willow)	
116	*Erwinia salicis*	Watermark
117	*Pseudomonas saliciperda*	Blight
	Solanum tuberosum (potato)	
118	*Bacillus* spp.	Storage rots
119	*Corynebacterium sepedonicum*	Ring rot
120	*Erwinia* spp.	Soft rot
121	*E. atroseptica*	Blackleg
122	*Pseudomonas solanacearum*	Brown rot
123	*Streptomyces scabies*	Scab
	Trifolium spp. (clover)	
124	*Pseudomonas cichorii*	Leaf blight
125	*P. radiciperda*	Root rot
126	*P. stizolobii*	Leaf spot
127	*P. syringae*	Leaf spot and blight
	Triticum aestivum (wheat)	
128	*Corynebacterium iranicum*	Spike blight
129	*C. tritici*	Spike blight
130	*Pseudomonas atrofaciens*	Basal glume rot
131	*Xanthomonas translucens undulosa*	Black chaff
	Ulmus spp. (elm)	
132	*Erwinia nimipressuralis*	Wetwood
133	*Pseudomonas lignicola*	Black streak of wood
134	*P. ulmi*	Leaf spot
	Vicia faba (broad bean)	
135	*Pseudomonas fabae*	Blight
	Vicia faba (broad bean)	
136	*Pseudomonas viciae*	Leaf and stem spot
	Vitis spp. (grape)	
137	*Agrobacterium tumefaciens*	Crown gall
138	*Erwinia vitivora*	Blight
139	*Xanthomonas vitis-carnosae*	Leaf spot
	Zea mays (corn)	
140	*Erwinia carotovora zeae*	Stalk rot and leaf blight
141	*E. dissolvens*	Stalk rot
142	*Pseudomonas alboprecipitans*	Leaf blight and stalk rot
143	*P. andropogonis*	Stripe
144	*P. desaiana*	Stinking rot
145	*P. lapsa*	Leaf and stalk rot
146	*Xanthomonas stewartii*	Wilt
	Fleshy vegetables[1]	
147	*Erwinia aroideae*	Soft rots
148	*E. atroseptica*	Soft rots
149	*E. carotovora*	Soft rots
150	*E. chrysanthemi*	Soft rots
	Numerous plants	
151	*Agrobacterium tumefaciens*	Crown gall
152	*Corynebacterium fascians*	Fasciation
153	*Erwinia amylovora*	Fire blight of Rosaceae
154	*E. aroideae*	Soft rot
155	*E. atroseptica*	Soft rot
156	*E. carotovora*	Soft rot
157	*E. chrysanthemi*	Soft rot
158	*Pseudomonas solanacearum*	Brown rot
159	*P. syringae*	Blight

/1/ Plants of tuberous and fleshy roots.

Contributors: (a) Dickey, Robert S., (b) Burkholder, W. H.

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137. FUNGAL PARASITES: PLANTS

Part I. FIELD, FRUIT, AND VEGETABLE CROPS

Most vegetable crops have damping-off and root rot caused by *Phytophthora* spp., *Pythium* spp., or *Rhizoctonia solani*.

	Host Plant and Pathogen (A)	Disease (B)
	Allium spp. (onion)	
1	*Botrytis* spp.	Neck rot
2	*Peronospora destructor*	Downy mildew
3	*Pyrenochaeta terrestris*	Pink rot
4	*Urocystis cepulae*	Smut
	Asparagus officinalis (garden asparagus)	
5	*Fusarium oxysporum*	Wilt, root rot
6	*Puccinia asparagi*	Rust

continued

137. FUNGAL PARASITES: PLANTS

Part I. FIELD, FRUIT, AND VEGETABLE CROPS

	Host Plant and Pathogen	Disease
	(A)	(B)
	Avena sativa (common oat)	
7	*Leptosphaeria avenaria*	Black stem
8	*Puccinia coronata*	Crown rust
9	*P. graminis*	Stem rust
10	*Ustilago avenae*	Loose smut
11	*U. kolleri*	Covered smut
	Beta vulgaris (common beet)	
12	*Aphanomyces cochlioides*	Black root, tip rot
13	*Cercospora beticola*	Cercospora leaf spot
14	*Fusarium* spp.	Root rot, storage rot, wilt
15	*Peronospora schachtii*	Downy mildew
16	*Pleospora betae*	Leaf spot, root rot
17	*Uromyces betae*	Rust
	Capsicum frutescens (bush red pepper)	
18	*Cercospora capsici*	Frogeye leaf spot
19	*Gloeosporium piperatum*	Anthracnose
20	*Phytophthora capsici*	Phytophthora blight
	Carya illinoensis (pecan)	
21	*Cercospora fusca*	Brown leaf spot
22	*Cladosporium effusum*	Scab
23	*Gnomonia caryae*	Liver spot
24	*G. nerviseda*	Vein spot
25	*Mycosphaerella caryigena*	Downy spot
26	*M. dendroides*	Leaf blotch
27	*Phymatotrichum cactorum*	Cotton root rot
	Citrus spp. (citrus)	
28	*Clitocybe tabescens*	Root rot
29	*Diaporthe citri*	Melanose, stem-end rot
30	*Diplodia natalensis*	Twig and branch dieback, stem-end rot
31	*Elsinoe fawcettii*	Scab
32	*Glomerella cingulata*	Withertip, anthracnose
33	*Phytophthora citrophthora*	Foot rot, brown rot
	Cucurbitaceae (cucumber, gourd, muskmelon, pumpkin, squash, watermelon)	
34	*Alternaria cucumerina*	Leaf blight
35	*Cladosporium cucumerinum*	Scab
36	*Colletotrichum lagenarium*	Anthracnose[1]
37	*Erysiphe cichoracearum*	Powdery mildew
38	*Fusarium oxysporum*	Fusarium wilt[2]
39	*F. oxysporum niveum*	Fusarium wilt[3]
40	*F. solani*	Fusarium root rot
41	*Mycosphaerella melonis*	Black rot
42	*Pseudoperonospora cubensis*	Downy mildew
43	*Verticillium albo-atrum*	Verticillium wilt
	Daucus carota (carrot)	
44	*Alternaria dauci*	Leaf blight
45	*A. radicina*	Black rot
46	*Cercospora carotae*	Blight, leaf spot
	Fragaria chiloensis (chiloe strawberry)	
47	*Botrytis cinerea*	Gray mold rot
48	*Dendrophoma obscurans*	Leaf blight, stem-end rot
49	*Diplocarpon earliana*	Leaf scorch
50	*Gnomonia fragariae*	Leaf and stem blight
51	*Mycosphaerella fragariae*	Leaf spot
52	*Phytophthora fragariae*	Red stele
53	*Verticillium albo-atrum*	Verticillium wilt
	Glycine soja (soybean)	
54	*Cephalosporium gregatum*	Brown stem rot
55	*Cercospora sojina*	Frogeye leaf spot
56	*Colletotrichum truncatum*	Anthracnose
57	*Corynespora cassiicola*	Target spot
58	*Diaporthe phaseolorum batatis*	Stem canker
59	*D. phaseolorum sojae*	Pod and stem blight
60	*Fusarium oxysporum tracheiphilum*	Fusarium wilt
61	*Glomerella glycines*	Anthracnose
62	*Macrophomina phaseoli*	Ashy stem blight
63	*Pellicularia rolfsii*	Southern wilt
64	*Peronospora manshurica*	Downy mildew
65	*Phyllosticta sojicola*	Leaf spot
66	*Phymatotrichum omnivorum*	Texas root rot
67	*Sclerotinia sclerotiorum*	Stem rot
68	*Septoria glycines*	Brown spot
	Gossypium spp. (cotton)	
69	*Fusarium oxysporum*	Fusarium wilt
70	*Glomerella gossypii*	Anthracnose
71	*Pellicularia filamentosa*	"Sore shin" seedling stem canker
72	*Phymatotrichum omnivorum*	Root rot
73	*Puccinia stakmanii*	Rust
74	*Verticillium albo-atrum*	Wilt
	Hordeum vulgare (barley)	
75	*Erysiphe graminis*	Powdery mildew
76	*Gibberella zeae*	Fusarium blight (scab)
77	*Helminthosporium gramineum*	Stripe disease
78	*H. sativum*	Spot blotch, root rot, foot rot, kernel blight
79	*Puccinia graminis*	Stem rust
80	*P. hordei*	Leaf rust
81	*Pyrenophora teres*	Net blotch
82	*Rhynchosporium secalis*	Scald
83	*Typhula itoana*	Snow mold
84	*Ustilago hordei*	Covered smut
85	*U. nigra*	Black or semiloose smut
86	*U. nuda*	Loose smut
	Ipomoea batatas (sweet potato)	
87	*Endoconidiophora fimbriata*	Black rot
88	*Fusarium oxysporum*	Wilt, stem rot
89	*Monilochaetes infuscans*	Scurf
90	*Plenodomus destruens*	Foot rot
91	*Streptomyces ipomoea*	Pox or soil rot
	Juglans regia (Persian walnut)	
92	*Armillaria mellea*	Root rot
93	*Ascochyta juglandis*	Ring spot
94	*Dothiorella gregaria*	Dieback, black sap
95	*Exosporina fawcetti*	Branch wilt, canker
96	*Gnomonia leptostyla*	Leaf blotch
97	*Phytophthora cactorum*	Crown rot
	Lactuca sativa (lettuce)	
98	*Botrytis cinerea*	Gray mold
99	*Bremia lactucae*	Downy mildew
	Lycopersicon esculentum (tomato)	
100	*Alternaria solani*	Early blight

/1/ Disease of cucurbitaceous plants other than squash. /2/ Disease of muskmelon. /3/ Disease of watermelon.

continued

137. FUNGAL PARASITES: PLANTS

Part I. FIELD, FRUIT, AND VEGETABLE CROPS

	Host Plant and Pathogen	Disease
	(A)	(B)
	Lycopersicon esculentum (tomato)	
101	*Colletotrichum phomoides*	Anthracnose
102	*Fusarium oxysporum*	Fusarium wilt
103	*Phoma destructiva*	Phoma rot
104	*Phytophthora infestans*	Late blight
105	*Septoria lycopersici*	Leaf spot
106	*Stemphylium solani*	Gray leaf spot
	Malus pumila (common apple)	
107	*Botryosphaeria ribis*	Botryosphaeria canker and fruit rot
108	*Clitocybe tabescens*	Root rot
109	*Corticium galactinum*	White root rot
110	*Gloeodes pomigena*	Sooty blotch
111	*Glomerella cingulata*	Bitter rot of fruit, stem canker
112	*Gymnosporangium juniperi*	Rust
113	*Phyllosticta solitaria*	Blotch, leaf spot, canker
114	*Podosphaera leucotricha*	Powdery mildew
115	*Venturia inaequalis*	Scab
116	*Xylaria mali*	Black root rot
	Medicago sativa (alfalfa)	
117	*Leptosphaeria pratensis*	Leaf spot, root rot, crown rot
118	*Peronospora trifoliorum*	Downy mildew
119	*Phoma herbarum medicaginis*	Spring black stem
120	*Pseudopeziza jonesii*	Yellow leaf blotch
121	*P. medicaginis*	Common leaf spot
122	*Sclerotinia trifoliorum*	Crown rot, root rot
123	*Uromyces striatus*	Rust
124	*Urophlyctis alfalfae*	Crown wart
	Nicotiana tabacum (common tobacco)	
125	*Cercospora nicotianae*	Frogeye leaf spot
126	*Fusarium oxysporum*	Fusarium wilt
127	*Macrophomina phaseoli*	Charcoal rot
128	*Pellicularia filamentosa*	Stem canker
129	*Peronospora tabacina*	Blue mold
130	*Phytophthora parasitica*	Black shank
131	*Thielaviopsis basicola*	Black rot
	Oryza sativa (rice)	
132	*Cercospora oryzae*	Cercospora spot
133	*Cochliobolus miyabeanus*	Helminthosporium blight
	Persea americana (American avocado)	
134	*Botryosphaeria ribis*	Branch canker, fruit rot
135	*Cercospora purpurea*	Cercospora spot or blotch
136	*Colletotrichum gloeosporioides*	Anthracnose or black spot
137	*Diplodia theobromae*	Stem-end rot
138	*Phomopsis* spp.	Stem-end rot
139	*Phytophthora cinnamomi*	Phytophthora root rot
140	*Sphaceloma perseae*	Scab[4]
141	*Verticillium albo-atrum*	Verticillium wilt
	Phaseolus vulgaris (kidney bean)	
142	*Colletotrichum lindemuthianum*	Anthracnose
143	*Erysiphe polygoni*	Powdery mildew
	Phaseolus vulgaris (kidney bean)	
144	*Fusarium phaseoli, F. solani*	Root rot
145	*Macrophomina phaseoli*	Ashy stem blight, charcoal rot, leaf spot, root rot
146	*Sclerotinia sclerotiorum*	White mold (sclerotinia wilt)
147	*Sclerotium rolfsii*	Southern blight
148	*Uromyces phaseoli*	Rust
	Pisum sativum (garden pea)	
149	*Aphanomyces euteiches*	Root rot
150	*Ascochyta pinodella*	Ascochyta foot rot
151	*A. pisi*	Ascochyta leaf and pod spot
152	*Colletotrichum pisi*	Anthracnose
153	*Erysiphe polygoni*	Powdery mildew
154	*Fusarium oxysporum pisi*, strain 1	Fusarium wilt
155	*F. oxysporum pisi*, strain 2	Near wilt
156	*F. solani*	Root rot
157	*Mycosphaerella pinodes*	Mycosphaerella blight
158	*Peronospora viciae*	Downy mildew
	Prunus amygdalus (almond)	
159	*Armillaria mellea*	Root rot
160	*Coryneum carpophilum*	Blight, shot hole
161	*Monilinia fructicola*	Peach brown rot
162	*M. laxa*	Brown rot, blossom blight
	Prunus domestica (garden plum)	
163	*Armillaria mellea*	Root rot
164	*Dibotryon morbosum*	Black knot
165	*Monilinia fructicola*	Brown rot, blossom blight
166	*M. laxa*	European brown rot, blossom and twig blight
	Prunus persica (peach)	
167	*Armillaria mellea*	Root rot
168	*Clitocybe tabescens*	Root rot
169	*Coryneum carpophilum*	Blight, shot hole
170	*Glomerella cingulata*	Ripe rot, twig blight
171	*Monilinia fructicola*	Brown rot, twig canker
172	*Taphrina deformans*	Leaf curl
	Pyrus communis (pear)	
173	*Botrytis cinerea*	Gray mold
174	*Clitocybe tabescens*	Root rot
175	*Neofabraea malicorticis*	Black spot canker
176	*N. perennans*	Perennial canker
177	*Podosphaera leucotricha*	Powdery mildew
178	*Venturia pyrina*	Scab
	Solanum tuberosum (potato)	
179	*Alternaria solani*	Early blight
180	*Fusarium* spp.	Wilt and tuber rot
181	*Phytophthora infestans*	Late blight
182	*Streptomyces scabies*	Common scab
183	*Verticillium albo-atrum*	Verticillium wilt
	Trifolium spp. (clover)	
184	*Colletotrichum trifolii*	Southern anthracnose

/4/ Disease of fruit and foliage.

continued

137. FUNGAL PARASITES: PLANTS

Part I. FIELD, FRUIT, AND VEGETABLE CROPS

	Host Plant and Pathogen	Disease
	(A)	(B)
	Trifolium spp. (clover)	
185	*Cymadothea trifolii*	Sooty blotch[5]
186	*Erysiphe polygoni*	Powdery mildew[6]
187	*Kabatiella caulivora*	Northern anthracnose[7]
188	*Phoma herbarum medicaginis*	Spring black stem[6]
189	*Pseudoplea trifolii*	Leaf spot
	Triticum aestivum (wheat)	
190	*Erysiphe graminis*	Powdery mildew
191	*Gibberella zeae*	Fusarium blight (scab)
192	*Helminthosporium sativum*	Crown rot, root rot
193	*Leptosphaeria nodorum*	Glume blotch, node canker
194	*Ophiobolus graminis*	Take-all
195	*Puccinia glumarum*	Stripe rust
196	*P. graminis*	Stem rust
197	*P. rubigo-vera*	Leaf rust
198	*Septoria tritici*	Leaf blotch
199	*Tilletia brevifaciens*	Dwarf bunt
200	*T. caries, T. foetida*	Bunt (stinking smut)
201	*Urocystis tritici*	Flag smut
202	*Ustilago tritici*	Loose smut

	Host Plant and Pathogen	Disease
	(A)	(B)
	Vitis spp. (grape)	
203	*Cryptosporella viticola*	Dead-arm
204	*Elsinoe ampelina*	Anthracnose
205	*Guignardia bidwellii*	Black rot
206	*Plasmopara viticola*	Downy mildew
207	*Uncinula necator*	Powdery mildew
	Zea mays (corn)	
208	*Cochliobolus heterostrophus*	Southern leaf blight, seedling blight
209	*Diplodia macrospora, D. zeae*	Stalk rot, dry ear rot
210	*Gibberella fujikuroi*	Pink ear rot, seedling blight
211	*G. zeae*	Stalk rot, red ear rot, seedling blight, root rot
212	*Helminthosporium carbonum*	Northern leaf spot, charred ear, seedling blight
213	*H. turcicum*	Northern leaf blight, seedling blight
214	*Physalospora zeae*	Gray ear rot
215	*Puccinia sorghi*	Rust
216	*Sclerospora graminicola*	Downy mildew
217	*Ustilago maydis*	Smut

/5/ Disease of red, white, and alsike clover. /6/ Disease of red clover. /7/ Disease of crimson and red clover.

Contributor: Andersen, Axel L.

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Part II. FOREST TREES

	Host Plant and Pathogen	Disease
	(A)	(B)
	Abies spp. (fir)	
1	*Adelopus gäumannii*	Swiss needle cast
2	*Aleurodiscus amorphus*	Aleurodiscus canker
3	*Armillaria mellea*	Shoestring root rot
4	*Bifusella abietis, B. faullii*	Needle cast
5	*Caeoma faulliana*	Needle rust
6	*Calyptospora goeppertiana*	Needle rust
7	*Cephalosporium* sp.	Cephalosporium canker
8	*Corticium galactinum*	Corticium rot

	Host Plant and Pathogen	Disease
	(A)	(B)
	Abies spp. (fir)	
9	*Cytispora abietis*	Cytispora canker
10	*Dasyscypha resinaria*	Dasyscypha canker
11	*Fomes annosus*	Root and butt rot
12	*F. pini*	Red ring rot
13	*F. pinicola*	Brown cubical rot
14	*Hyalopsora aspidiotus*	Needle cast
15	*Hypoderma robustum*	Needle cast

continued

137. FUNGAL PARASITES: PLANTS

Part II. FOREST TREES

	Host Plant and Pathogen	Disease
	(A)	(B)
	Abies spp. (fir)	
16	*Hypodermella abietis, H. mirabilis, H. nervata*	Needle cast
17	*Lophodermium abietis, L. uncinatum*	Needle cast
18	*Melampsora abieti-capraearum*	Needle rot
19	*Melampsorella cerastii*	Witches'-broom
20	*Milesia fructuosa, M. marginalis*	Needle rust
21	*M. pycnograndis*	Needle-witches'-broom rust
22	*Peridermium holwayi, P. ornamentale, P. rugosum*	Needle rust
23	*Phacidium infestans*	Needle blight
24	*Phomopsis boycei*	Phomopsis canker
25	*Polyporus abietinus*	White, pitted sap rot
26	*P. balsameus*	Brown butt rot
27	*P. dryadeus*	White root rot
28	*P. schweinitzii*	Root and butt rot
29	*Poria subacida*	Butt rot
30	*Rehmiellopsis balsamiae*	Tip blight
31	*Scleroderris abieticola*	Scleroderris canker
32	*Spicaria anomala*	Brown stain of fir
33	*Stereum chailleti*	Patchy rot
34	*S. sanguinolentum*	Red heartrot
35	*Uredinopsis atkinsonii, U. ceratophora, U. longimucronata, U. macrosperma, U. mirabilis*	Needle rust
	Acer spp. (maple)	
36	*Cristulariella depraedens*	Leaf spot and wilt
37	*Daedalea unicolor*	Rot, canker
38	*Daldinia concentrica*	White rot
39	*Endoconidiophora virescens*	Sapstreak
40	*Eutypella parasitica*	Eutypella canker
41	*Fomes connatus*	Butt rot
42	*F. igniarius*	Heartrot
43	*Hydnum septentrionale*	Soft, spongy white rot
44	*Hymenochaete agglutinans*	Hymenochaete canker
45	*Hypoxylon blakei*	Hypoxylon canker
46	*Nectria cinnabarina*	Nectria dieback
47	*N. galligena*	Nectria canker
48	*Phleospora aceris*	Leaf spot
49	*Phytophthora cactorum*	Bleeding canker
50	*Polyporus glomeratus*	Rot, canker
51	*Rhytisma acerinum*	Tar spot
52	*Schizoxylon microsporum*	Schizoxylon canker
53	*Stereum murrayi*	Rot, canker
54	*Uncinula circinata*	Powdery mildew
55	*Venturia acerina*	Red-brown spot
56	*Verticillium albo-atrum*	Verticillium wilt
57	*Xylaria digitata*	Xylaria root rot
	Alnus spp. (alder)	
58	*Cytispora pulcherrima*	Cytispora canker
59	*Didymosphaeria oregonensis*	Didymosphaeria canker
60	*Erysiphe aggregata*	Powdery mildew
61	*Melampsoridium alni*	Leaf rust
62	*Taphrina amentorum, T. occidentalis, T. robinsoniana, T. rugosa*	Leaf blister
63	*T. macrophylla*	Yellow leaf blister
	Betula spp. (birch)	
64	*Fomes fomentarius*	White mottled rot
65	*F. igniarius*	Heartrot, canker
66	*Melampsoridium betulinum*	Leaf rust
67	*Nectria galligena*	Nectria canker
68	*Pholiota squarrosa*	Brown mottled rot
69	*Poria obliqua*	Canker
70	*Stereum murrayi*	Rot, canker
71	*Taphrina boycei, T. flava*	Yellow leaf blister
	Cupressus arizonica (Arizona cypress)	
72	*Gymnosporangium cupressi*	Fusiform gall rust of juniper
	Fagus grandifolia (American beech)	
73	*Fomes fomentarius*	White mottled rot
74	*F. igniarius*	Heartrot
75	*Nectria coccinea*	Beech bark disease
76	*Phytophthora cactorum*	Phytophthora blight
77	*Polyporus glomeratus*	Light-brown spongy heartrot
78	*Poria obliqua*	Canker
	Fraxinus spp. (ash)	
79	*Armillaria mellea*	Root rot
80	*Cytispora annularis*	Cytispora canker
81	*Fomes fraxinophilus*	White heartrot
82	*Marssonina fraxini*	Leaf spot
83	*Mycosphaerella fraxinicola*	Leaf spot
84	*Phymatotrichum omnivorum*	Phymatotrichum root rot
85	*Polyporus hispidus*	Spongy white rot
86	*Puccinia peridermiospora*	Leaf rust
	Juglans nigra (black walnut)	
87	*Armillaria mellea*	Shoestring root rot
88	*Fomes everhartii*	White heartrot
89	*Phymatotrichum omnivorum*	Phymatotrichum root rot
90	*Phytophthora cinnamomi*	Root rot
	Juniperus spp. (juniper)	
91	*Coccodothis sphaeroidea*	Leaf blight
92	*Fomes juniperinus*	Juniper pocket rot
93	*F. subroseus*	Brown pocket rot
94	*Gymnosporangium aurantiacum*	Mountain ash and mountain juniper rot
95	*G. bermudianum*	Juniper rust
96	*G. betheli*	Elongate gall rust of juniper
97	*G. clavariaeforme, G. clavipes*	Fusiform gall rust of juniper
98	*G. corniculans*	Serviceberry-juniper rust
99	*G. davisii*	Chokeberry-mountain juniper rust
100	*G. effusum*	Fusiform gall rust of juniper
101	*G. exiguum*	Hawthorne-alligator juniper rust
102	*G. externum*	Porteranthus, fusiform gall rust of juniper
103	*G. floriforme*	Hawthorne-juniper rust

continued

137. FUNGAL PARASITES: PLANTS

Part II. FOREST TREES

	Host Plant and Pathogen	Disease
	(A)	(B)
	Juniperus spp. (juniper)	
104	*Gymnosporangium globosum*	Hawthorne-cedar rust
105	*G. harnessianum*	Serviceberry-western juniper rust
106	*G. inconspicuum*	Serviceberry-Utah twig rust
107	*G. juniperi-virginianae*	Apple-cedar rust
108	*G. kernianum*	Witches'-broom
109	*G. multiporum*	Utah juniper rust
110	*G. nelsoni*	Hawthorne-western juniper rust
111	*G. trachysorum*	Fusiform gall rust of juniper
112	*G. tuberlatum*	Globoid gall rust of mountain juniper
113	*G. vauqueliniae*	Witches'-broom of vauquelinia
114	*Phomopsis juniperovora*	Juniper blight
	Larix occidentalis (western larch)	
115	*Fomes laricis*	Brown trunk rot
116	*Hypodermella laricis*	Needle cast
117	*Melampsora bigelowii, M. medusae*	Needle rust
118	*Sparassis radicata*	Sparassis root rot
	Picea glauca (white spruce)	
119	*Chrysomyxa cassandrae, C. chiogenis, C. empetri, C. ledi, C. ledicola*	Needle rust
120	*C. pyrolae*	Spruce cone rust
121	*Peridermium coloradense*	Witches'-broom
122	*Pucciniastrum americanum, P. arctium*	Needle rust
123	*Rhizina inflata*	Rhizina root rot
	Pinus ponderosa (western yellow pine)[1]	
124	*Atropellis arizonica, A. piniphila*	Atropellis canker
125	*Coleosporium solidaginis*	Needle rust
126	*Cronartium comandrae*	Comandra blister rust
127	*C. comptoniae*	Sweet-fern blister rust
128	*C. filamentosum*	Paintbrush blister rust
129	*C. harknessii*	Western gall rust
130	*C. quercuum*	Gall rust
131	*Dasyscypha ellisiana*	Dasyscypha canker
132	*Elytroderma deformans*	Witches'-broom, needle cast
133	*Fomes laricis*	Brown cubical rot
134	*F. pini*	Red ring rot
135	*Hypodermella medusa*	Needle cast
136	*Lentinus lepideus*	Brown cubical rot
	Pinus strobus (eastern white pine)[2,3]	
137	*Armillaria mellea*	Shoestring root rot
138	*Atropellis pinicola*	Atropellis canker
139	*Bifusella linearis*	Needle cast
140	*Caliciopsis pinea*	Caliciopsis canker
141	*Cronartium ribicola*	White pine blister rust
142	*Fomes annosus*	Root and butt rot
	Pinus strobus (eastern white pine)[2,3]	
143	*Fomes laricis*	Brown cubical rot
144	*F. pini*	Red ring rot
145	*Hypoderma desmazierii*	Needle cast
146	*Lentinus lepideus*	Brown cubical rot
147	*Lophodermium pinastri*	Needle cast
148	*Neopeckia coulteris*	Brown felt blight
149	*Phacidium planum*	Needle blight
150	*Polyporus circinatus*	Red root and butt rot
151	*Sparassis radicata*	Sparassis root rot
	Populus spp. (poplar)	
152	*Armillaria mellea*	Shoestring root rot
153	*Ciborinia whetzelii*	Ink spot
154	*Cytispora chrysosperma*	Cytispora canker
155	*Dothichiza populea*	Dothichiza canker
156	*Fomes applanatus*	White butt rot
157	*F. fomentarius*	White mottled rot
158	*F. igniarius*	White heartrot
159	*Fusicladium radiosum*	Shoot blight
160	*Hypoxylon pruinatum*	Hypoxylon canker
161	*Linospora tetraspora*	Leaf blight
162	*Marssonina populi*	Leaf spot, shoot blight
163	*Melampsora bigelowii, M. medusae, M. occidentalis*	Leaf spot
164	*Nectria galligena*	Nectria canker
165	*Neofabraea populi*	Neofabraea canker
166	*Sclerotina bifrons*	Ink spot
167	*Septoria musiva*	Septoria canker
168	*S. populicola*	Leaf spot
169	*Taphrina aurea*	Yellow leaf blister
170	*T. johansonii*	Catkin blister
171	*Trametes suavcolens*	Soft white rot
172	*Uncinula salicis*	Powdery mildew
173	*Valsa nivea, V. sordida*	Valsa canker
174	*Xylaria digitata*	Xylaria root rot
	Quercus spp. (oak)	
175	*Aleurodiscus oaksii*	Smooth patch
176	*Armillaria mellea*	Shoestring root rot
177	*Cronartium cerebrum*	Globose gall rust
178	*C. fusiforme*	Southern fusiform rust
179	*C. strobilinum*	Pinecone rust
180	*Daedalea quercina*	Brown cubical rot
181	*Endoconidiophora fagacearum*	Oak wilt
182	*Fistulina hepatica*	Brown cubical rot
183	*Fomes everhartii*	White heartrot
184	*Gnomonia veneta*	Anthracnose
185	*Hydnum erinaceus*	White rot
186	*Morenoella quercina*	Leaf spot
187	*Polyporus berkeleyi*	White butt rot
188	*P. croeceus*	White pocket rot
189	*P. dryophilus*	Piped rot
190	*P. frondosus*	Butt rot
191	*P. hispidus*	Heartrot, canker
192	*P. spraguei*	White rot
193	*P. sulphureus*	Brown cubical rot
194	*Sphaeropsis quercina*	Sphaeropsis canker
195	*Sphaerotheca lanestris*	Witches'-broom
196	*Stereum gausapatum*	White mottled rot

/1/ Hardwood. /2/ Softwood. /3/ Data also apply to other softwood pines: *P. lambertiana* (sugar pine), *P. monticola* (western white pine).

continued

137. FUNGAL PARASITES: PLANTS

Part II. FOREST TREES

	Host Plant and Pathogen	Disease
	(A)	(B)
	Quercus spp. (oak)	
197	*Stereum subpileatum*	White pocket rot
198	*Strumella coryneoidea*	Strumella canker
199	*Taphrina caerulescens*	Oak leaf blister
	Salix spp. (willow)	
200	*Botryosphaeria ribis*	Botryosphaeria canker
201	*Cytispora pulcherrima*	Cytispora canker
202	*Fomes igniarius*	Heartrot
203	*Fusicladium saliciperdum*	Willow scab
204	*Melampsora abieti-capraearum*	Leaf rust
205	*Physalospora miyabeana*	Black canker
206	*Polyporus squamosus*	White rot
207	*Trametes suaveolens*	Soft white rot
208	*Uncinula salicis*	Powdery mildew
209	*Valsa nivea, V. sordida*	Valsa canker
	Sequoia sempervirens (redwood)	
210	*Poria albipellucida*	White ring rot
211	*P. sequoia*	Brown pocket rot
	Thuja occidentalis (northern white cedar)	
212	*Coniophora puteana*	Brown cubical rot
213	*Keithia thujina*	Cedar leaf blight
	Tsuga canadensis (eastern hemlock)	
214	*Fomes robustus-tsugina*	White heartrot
	Tsuga canadensis (eastern hemlock)	
215	*Ganoderma lucidum*	White rot
216	*Keithia tsugae*	Cedar leaf blight
217	*Melampsora abietis, M. farlowii*	Needle rust
218	*Polyporus borealis*	White mottled rot
219	*Pucciniastrum hydrangeae, P. myrtilli*	Needle rust
220	*Rosellinia herpotrichoides*	Brown felt blight
	Ulmus spp. (elm)	
221	*Ceratostomella ulmi*	Dutch-elm disease
222	*Chalaropsis thielavioides*	Chinese-elm root rot
223	*Cytispora ambiens*	Cytispora canker
224	*Dothiorella ulmi*	Dieback
225	*Gloeosporium ulmicolum*	Leaf spot
226	*Gnomonia ulmea*	Leaf spot
227	*Phleospora ulmi*	Elm leaf spot
228	*Phytophthora inflata*	Pit canker
229	*Pleurotus ulmaris*	Brown rot
230	*Sphaeropsis ulmicola*	Canker
231	*Tubercularia* sp.	Elm canker
232	*Uncinula macrocarpa*	Powdery mildew
233	*Verticillium* spp.	Verticillium wilt
234	*V. rhizophagum*	Verticillium root disease

Contributor: Baxter, Dow V.

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138. MISTLETOE PARASITES: FOREST TREES

In forest trees, witches'-broom is the chief disease caused by mistletoe.

	Host (Common Name)	Parasite (Common Name)
	(A)	(B)
1	*Abies* spp. (fir)	*Phoradendron pauciflorum* (western fir mistletoe)/1/
2	*Abies anabilis* (Cascade fir), *A. concotor* (white fir), *A. grandis* (grand fir), *A. lasiocarpa* (alpine fir), *A. lasiocarpa arizonica* (cork-bark fir)	*Arceuthobium campylopodum abietinum* (western dwarf mistletoe)
3	*Acer* spp. (maple)	*Phoradendron flavescens* (American mistletoe)
4	*Alnus* spp. (alder)	*Phoradendron macrophyllum* (big-leaf mistoe)
5	*Cupressus* spp. (cypress)	*Phoradendron densum* (cypress mistletoe)
6	*Fraxinus* spp. (ash)	*Phoradendron longispicum* (long-spiked mistletoe)

/1/ Leader injury.

continued

138. MISTLETOE PARASITES: FOREST TREES

	Host (Common Name)	Parasite (Common Name)
	(A)	(B)
7	*Fraxinus* spp. (ash)	*Phoradendron macrophyllum* (big-leaf mistletoe)
8	*Juglans* spp. (walnut)	*Phoradendron longispicum* (long-spiked mistletoe)
9		*P. macrophyllum* (big-leaf mistletoe)
10	*Juniperus* spp. (juniper)	*Phoradendron densum* (cypress mistletoe)
11		*P. juniperinum* (juniper mistletoe)
12		*P. ligatum* (pinch-scale mistletoe)
13	*Larix laricina* (eastern larch)	*Arceuthobium pusillum* (dwarf mistletoe)
14	*Larix lyalli* (alpine larch), *L. occidentalis* (western larch)	*Arceuthobium campylopodum laricis* (western dwarf mistletoe)
15	*Picea breweriana* (Brewer spruce), *P. engelmanni* (Engelmann spruce), *P. pungens* (Colorado spruce)	*Arceuthobium campylopodum microcarpum* (western dwarf mistletoe)
16	*Picea glauca* (white spruce)[a], *P. mariana* (black spruce), *P. rubens* (red spruce)[a]	*Arceuthobium pusillum* (dwarf mistletoe)
17	*Pinus albicaulis* (whitebark pine), *P. aristata* (bristlecone pine), *P. balfouriana* (foxtail pine), *P. flexilis* (limber pine)	*Arceuthobium campylopodum cyanocarpum* (western dwarf mistletoe)
18	*Pinus attenuata* (knobcone pine)[a], *P. contorta latifolia* (lodgepole pine)[a], *P. coulteri* (Coulter pine), *P. jeffreyi* (Jeffrey pine), *P. ponderosa* (western yellow pine), *P. radiata* (Monterey pine), *P. sabinana* (digger pine)	*Arceuthobium campylopodum typicum* (western dwarf mistletoe)
19	*Pinus cembroides* (Mexican piñon pine) and other piñons	*Arceuthobium campylopodum divaricatum* (piñon mistletoe)
20	*Pinus contorta latifolia* (lodgepole pine)	*Arceuthobium americanum* (lodgepole pine dwarf mistletoe)
21	*Pinus lambertiana* (sugar pine), *P. monticola* (western white pine), *P. reflexa* (Mexican white pine)	*Arceuthobium campylopodum* [illegible] (western dwarf mistletoe)
22	*Pinus latifolia* (Apache pine), *P. leiophylla chihuahuana* (chihuahua pine), *P. ponderosa arizonica* (Arizona ponderosa pine)	*Arceuthobium vaginatum* (southwestern dwarf mistletoe)
23	*Pinus ponderosa scopulorum* (Rocky Mountain ponderosa pine)	*Arceuthobium vaginatum cryptopodum* (Rocky Mountain ponderosa pine mistletoe)
24	*Populus* spp. (poplar)	*Phoradendron longispicum* (long-spiked mistletoe)
25		*P. macrophyllum* (big-leaf mistletoe)
26	*Quercus* spp. (oak)	*Phoradendron engelmanni* (Texas mistletoe)
27		*P. flavescens* (American mistletoe)
28		*P. longispicum* (long-spiked mistletoe)
29		*P. villosum* (Pacific mistletoe)
30	*Salix* spp. (willow)	*Phoradendron longispicum* (long-spiked mistletoe)
31		*P. macrophyllum* (big-leaf mistletoe)
32	*Tsuga heterophylla* (western hemlock), *T. mertensiana* (mountain hemlock)	*Arceuthobium campylopodum tsugensis* (western dwarf mistletoe)
33	*Ulmus* spp. (elm)	*Phoradendron engelmanni* (Texas mistletoe)
34		*P. flavescens* (American mistletoe)

/a/ Rarely serves as host.

Contributor: Baxter, Dow V.

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	Species	Disease	Natural Occurrence in Animals Other than Man	Microscopic Appearance in Man Skin
	(A)	(B)	(C)	(D)
1	*Cladosporium werneckii*	Tinea nigra	None	Pigmented (light brown to dark green), branching, septate hyphae; may develop closely septate swollen cells and chlamydospores
2	*Epidermophyton flocossum*	Tinea pedis, T. cruris, T. unguium	None	Abundant-branching, septate hyphae; may segment into chains of arthrospores
3	*Malassezia furfur*	Tinea versicolor	None	Clusters of spherical, thick-walled, budding cells, 3-8 μ, and short irregular hyphae
4	*Microsporum audouinii*	Tinea capitis, T. corporis	Dog (rare), monkey (rare)	Branching, septate hyphae; may segment into chains of arthrospores
5	*M. canis*	Tinea capitis, T. corporis, T. barbae, T. unguium	Cat[1], chinchilla, dog[1], horse, monkey	Branching, septate hyphae; may segment into chains of arthrospores
6	*M. distortum*	Tinea capitis, T. corporis	Dog, monkey[1]	Branching, septate hyphae; may segment into c[illegible]ins of arthrospores
7	*M. gypseum*[2]	Tinea capitis, T. corporis	Cat, dog[1], horse[1], monkey, mouse, rat	Branching, septate hyphae; may segment into chains of arthrospores
8	*M. nanum*	Tinea capitis, T. corporis	Swine	Branching, septate hyphae; may segment into chains of arthrospores
9	*M. vanbreuseghemii*	Tinea capitis	Dog, Malabar squirrel	Branching, septate hyphae; may segment into chains of arthrospores
10	*Piedraia hortai*	Black piedra	Primates	None
11	*Trichophyton concentricum*	Tinea imbricata	None	Abundant-branching, septate hyphae; may segment into chains of arthrospores
12	*T. ferrugineum*	Tinea capitis, T. corporis	None	Branching, septate hyphae; may segment into chains of arthrospores
13	*T. gallinae*	Tinea capitis, T. corporis	Dog, poultry[1], wild birds	Branching, septate hyphae (rare)
14	*T. megninii*	Tinea barbae, T. capitis, T. unguium, T. corporis	Cattle?	Branching, septate hyphae
15	*T. mentagrophytes*	Tinea pedis, T. cruris, T. corporis, T. capitis, T. unguium, T. barbae	Many domestic and wild animals	Branching, septate hyphae; may segment into chains of arthrospores
16	*T. rubrum*	Tinea pedis, T. unguium, T. cruris, T. corporis, T. barbae, T. capitis	Cattle (rare), dog (rare)	Branching, septate hyphae; may segment into chains of arthrospores
17	*T. schoenleinii*	Favus, Tinea capitis, T. corporis, T. unguium	Dog (rare)	Abundant hyphae; may segment into chains of arthrospores throughout cellular debris of scutulum
18	*T. tonsurans*	Tinea capitis, T. corporis, T. unguium	None	Branching, septate hyphae; may segment into chains of arthrospores
19	*T. verrucosum*	Tinea corporis, T. capitis, T. barbae	Cattle[1], dog (rare), donkey, goat, horse, sheep	Branching, septate hyphae; may segment into chains of arthrospores

/1/ The more common hosts. /2/ A common saprophyte in soil.

MYCOSES

Microscopic Appearance in Man		Microscopic Appearance of Culture on Sabouraud's Agar	
Nail	Hair		
(E)	(F)	(G)	
None	None	Pigmented hyphae produce blastopores laterally, and 1-3 septate conidia in clusters or in short chains from apiculi or short conidiophores	1
Branching, septate hyphae; may segment into chains of arthrospores	None	Macroconidia abundant, clavate, 2-6 cells, blunt-tipped, smooth thin walls; occur in clusters of 2 or 3; no microconidia; abundant chlamydospores	2
None	None	No culture method available	3
None	Ectothrix; sheath of small spores, 2-3 μ	Hyphae with chlamydospores; microconidia infrequent, clavate, 2.5-4 x 3-6 μ; macroconidia rare, rudimentary, ill-formed	4
Rare	Ectothrix; sheath of small spores, 2-3 μ	Macroconidia numerous, 8-15 cells, spindle-shaped, thick rough walls, 8-15 x 40-150 μ; microconidia few, clavate, 2-4 x 3-6 μ	5
None	Ectothrix; sheath of small arthrospores, 2-3 μ	Macroconidia numerous, rough thick walls, distorted in shape, 4-14 x 3-40 μ; microconidia numerous, pyriform, 2-4 x 3-6 μ	6
None	May be sheath of small arthrospores, 2-3 μ; more commonly large-spored ectothrix, 5-8 μ; invasion frequently limited to hyphae inside hair	Macroconidia numerous, 4-6 cells, ellipsoid; thin rough walls, 8-12 x 30-50 μ; microconidia few, clavate	7
None	Septate and nonseptate hyphae, air bubbles inside hair	Macroconidia numerous, 2-3 cells, pyriform-to-elliptical, thin walls, finely echinulate or smooth, 5-7 x 12-18 μ; microconidia few	8
None	Closely septate hyphae inside hair	Macroconidia numerous, 7-10 cells, cylindro-fusiform, thick walls, densely echinulate, 10 x 60 μ; microconidia few to abundant, pyriform-to-obovate, 4 x 9 μ	9
None	Nodule on hair shaft consists of brown, dichotomously branched, closely septate hyphae, 4-8 μ diameter, and asci containing 2-8 ascospores	Dark, thick-walled, elosely septate hyphae, chlamydospores	10
None	None	Branching, septate, irregular hyphae, with chlamydospores, pectinate hyphae, favic chandeliers	11
None	Ectothrix; sheath of small arthrospores, 2-3 μ	Mycelium with occasional hyphal swellings; arthrospores, chlamydospores	12
None	Ectothrix; chains of large spores, 4-8 μ	Macroconidia usually numerous, 2-10 cells, clavate, smooth and slightly thickened walls; microconidia few, small, pyriform-to-elongate	13
Branching, septate hyphae; may segment into chains of arthrospores	Ectothrix; chains of large spherical arthrospores, 6-8 μ	Microconidia numerous, small pyriform to elongate; macroconidia rare, 2-8 cells, slightly clavate	14
Branching, septate hyphae; may segment into chains of arthrospores	Ectothrix; chains of small arthrospores, 3-5 μ	Microconidia numerous, subspherical-to-pyriform, in terminal clusters or singly along hyphae; macroconidia clavate, 2-5 cells, thick walls, 4-6 x 10-50 μ	15
Branching, septate hyphae; may segment into chains of arthrospores	Ectothrix; chains of large arthrospores, approximately 5 μ	Microconidia numerous, singly along hyphae and in clusters; macroconidia infrequent, pencil-shaped thin walls, 4-6 x 10-50 μ	16
Branching, septate hyphae; may segment into chains of arthrospores	Endothrix; hyphae, occasional arthrospore, and numerous air bubbles inside hair	Irregular hyphae, chlamydospores, hyphal swellings, pectinate hyphae, favic chandeliers	17
Rare	Endothrix; large spores in chains, 4-7.5 μ	Microconidia numerous, clavate along sides of hyphae or on short conidiophores; spore-bearing hyphae stain poorly with Lacto-Phenol Cotton Blue; numerous chlamydospores; thin, smooth-walled macroconidia rare	18
None	Ectothrix; chains of large arthrospores, 5-10 μ	Irregular hyphae, abundant chlamydospores; best growth at 37°C	19

continued

Part I. SUPERFICIAL

	Species	Disease	Natural Occurrence in Animals Other than Man	Microscopic Appearance in Man: Skin
	(A)	(B)	(C)	(D)
20	*Trichophyton violaceum*	Tinea capitis, T. corporis, T. barbae, T. unguium	Cattle (rare)	Branching, septate hyphae; may segment into chains of arthrospores
21	*Trichosporon beigelii*	White piedra	Monkey	None

Contributors: (a) Halde, Carlyn, (b) Georg, Lucille K., (c) Friedman, Lorraine

References: [1] Ainsworth, G. C. 1952. Medical mycology. Pitman, New York. [2] Ainsworth, G.C., and P. K. C. Public Health Serv. Publ. 994. [4] Conant, N. F., et al. 1954. Manual of clinical mycology. W. B. Saunders, 1963. Medical mycology. Lea and Febiger, Philadelphia. [7] Kaplan, W. 1959. J. Am. Vet. Med. Assoc. 134(3): et al. 1958. An introduction to medical mycology. Yearbook, Chicago. [10] Wilson, J. W. 1957. Clinical and

Part II. DEEP

	Species	Disease Produced (Synonym)	Geographical Distribution	Occurrence in Nature: Animal Host	Occurrence in Nature: Saprophytic Occurrence	Organs and Tissues of Man Frequently Attacked
	(A)	(B)	(C)	(D)	(E)	(F)
1	*Absidia corymbifera, A. ramosa, Basidiobolus ranarum, Rhizopus arrhizus, R. oryzae*	Phycomycosis	Worldwide	Birds, cattle, dog, horse, swine	Soil	Lung, brain, eye, intestinal tract, sinus, cutaneous and subcutaneous tissues
2	*Actinomyces israelii*	Actinomycosis	Worldwide	Rarely cattle	Man	Cervicofacial region, lung, bone, cecum, appendix, liver
3	*Allescheria boydii, Cephalosporium* spp., *Leptosphaeria senegalensis, Madurella* spp., *Phialophora jeanselmei, Pyrenochaeta romeroi*	Mycetoma (maduromycosis, Madura foot)	Worldwide, more frequent in tropics	None	Soil (*A. boydii, P. jeanselmei*)	Feet, hands, cutaneous and subcutaneous tissue, bone
4	*Aspergillus* spp.	Aspergillosis	Worldwide	Birds, cattle	Grain, soil	Ear, sinus, orbit, vagina, lung, brain
5	*Blastomyces dermatitidis*	North American blastomycosis	United States, Canada, Mexico	Dog, horse	Soil	Lung, skin, bone
6	*Candida albicans*	Candidiasis (moniliasis, thrush, mycotic vulvovaginitis)	Worldwide	Cattle, young swine, poultry	Man (often), soil (rare)	Mucous membranes, nail, skin, bronchus, lung, vagina
7	*Coccidioides immitis*	Coccidioidomycosis (coccidioidal granuloma, valley fever, Posada-Wernicke's disease)	Arid southwestern United States, Mexico, Cen. America, Chaco region and arid areas of northern S. America	Cattle, dog, horse, monkey, rodents, sheep	Soil	Lung, skin, bone, meninges

/1/ Animals are often difficult or even impossible to infect because of the great variation in susceptibility. /2/ Such

PARASITES: MAN

MYCOSES

Microscopic Appearance in Man		Microscopic Appearance of Culture on Sabouraud's Agar	
Nail	Hair		
(E)	(F)	(G)	
Branching, septate hyphae; may segment into chains of arthrospores	Endothrix; chains of large arthrospores, 4-7.5 μ	Irregular hyphae, abundant chlamydospores and hyphal swellings; microconidia rare	20
None	Nodule on hair shaft consists of hyphae which segment into spherical-to-rectangular cells, 2-8 μ; budding cells present	Hyphae segment into rectangular-to-spherical arthrospores; budding cells present	21

Austwich. 1958. Commonwealth Agr. Bur. (Gt. Brit.) Animal Health Rev. Ser. 6. [3] Ajello, L., et al. 1963. U.S. Philadelphia. [5] Dodge, C. W. 1935. Medical mycology. C. V. Mosby, St. Louis. [6] Emmons, C. W., et al. 113-117. [8] Langeron, M., and R. Vanbruseghem. 1952. Précis de mycologie. G. Masson, Paris. [9] Lewis, G., immunologic aspects of fungus disease. C. C. Thomas, Springfield.

MYCOSES

Susceptible Laboratory Animals[1]	Microscopic Appearance			
	In Human Tissue	Of Culture at 25°C	Of Culture at 37°C	
(G)	(H)	(I)	(J)	
Diabetic rabbit and rat	Nonseptate, coenocytic hyphae, 6-15 μ in width	Broad, coenocytic mycelium with sporangiophores	Similar to growth at 25°C	1
Hamster, mouse	Granules of filamentous, branching, gram-positive hyphae, 1 μ or less in width; club-shaped accretions on tips of hyphae may be present	Grows slowly	Microaerophilic-to-anaerobic, filamentous, branching, gram-positive hyphae, 1 μ or less in width; organism grows only on enriched media[2]	2
Mouse (*A. boydii*)	Oval, irregular-shaped granules, 0.5-2 mm, made up of segmented, branched, hyaline or brown hyphae, 2-5 μ diameter, and chlamydospores	*A. boydii:* mycelium with oval-to-pyriform conidia, 5-7 x 8-10 μ, borne singly at ends of long conidiophores; dark brown, thin-walled perithecia, 50-200 μ diameter, containing evanescent asci and elliptical ascospores; coremia occasionally present	Similar to cultures at 25°C	3
Birds, guinea pig, rabbit	Branching, septate hyphae	Conidiophore forms vesicle at tip; surface covered with sterigmata bearing long chains of conidia	Similar to growth at 25°C	4
Guinea pig, mouse	Single-budding, thick-walled cells, 8-15 μ	Mycelium with oval-to-pyriform conidia, 3-5 μ, on conidiophores or attached directly to hyphae	Similar to forms observed in tissue	5
Guinea pig, mouse, rabbit, rat	Oval-to-spherical budding cells, 2-4 μ; frequently hyphae which may show clusters of blastospores attached at septations	Oval-to-spherical, single-budding cells, 2-4 μ; pseudohyphae and hyphae; clusters of budding cells often at septations; thick-walled chlamydospores, 6-9 μ, on special medium	Similar to growth at 25°C	6
Guinea pig, hamster, mouse, other rodents	Thick-walled spherules, 20-60 μ, containing endospores, 2-5 μ	Mycelium with arthrospores, 2.5-3 x 3-4 μ, alternating with empty cells	Similar to growth at 25°C; under special conditions with special media, tissue spherules obtained in vitro	7

as beef heart infusion agar at pH 6.8-7.5.

continued

	Species	Disease Produced (Synonym)	Geographical Distribution	Occurrence in Nature: Animal Host	Occurrence in Nature: Saprophytic Occurrence	Organs and Tissues of Man Frequently Attacked
	(A)	(B)	(C)	(D)	(E)	(F)
8	*Cryptococcus neoformans*	Cryptococcosis (torulosis, European blastomycosis, Busse-Buschke disease)	Worldwide	Cat, cattle, dog, horse, monkey	Soil, bird droppings	Central nervous system, lung, skin, bone
9	*Geotrichum candidum*	Geotrichosis	Worldwide	Rodents	Soil, milk products, fruit	Mouth, intestinal tract, bronchus, lung
10	*Histoplasma capsulatum*	Histoplasmosis (reticuloendothelial cytomycosis, Darling's disease)	At least 30 countries	Cat, cattle, dog, horse, mouse, rat, skunk	Soil, especially from avian and bat habitats	Lung, liver, spleen, lymph nodes, mucous membranes, adrenal, kidney
11	*H. duboisii*	African histoplasmosis	Africa	Baboon, monkey	None	Lung, skin, bone, lymph nodes, spleen, liver
12	*Nocardia asteroides, N. brasiliensis*	Nocardiosis	Worldwide	Cat, cattle, dog	Soil	Lung, brain, kidney, heart, spleen, liver
13	*N. asteroides, N. brasiliensis, Streptomyces madurae, S. pelletieri, S. somaliensis*	Actinomycotic mycetoma	Worldwide, more frequent in tropics	None	None	Skin, subcutaneous tissue, bone, usually on lower extremities
14	*Paracoccidioides brasiliensis*	Paracoccidiomycosis (paracoccidioidal granuloma, Lutz-Splendore-Almeida disease)	S. & Cen. America, Mexico	None	None	Mouth, lung, lymph nodes, gastrointestinal tract
15	*Phialophora compactum, P. dermatitidis, P. pedrosoi, P. verrucosa, Cladosporium carrionii*	Chromoblastomycosis (chromomycosis, verrucous dermatitis)	Worldwide, more frequent in tropics	None	Soil, wood (*P. dermatitidis, P. verrucosa, C. carrionii*)	Usually on lower extremities, cutaneous and subcutaneous tissue, lymphatics
16	*Rhinosporidium seeberi*	Rhinosporidiosis	Worldwide, most frequent in India and Ceylon	Cattle, horse, mule	None	Mucous membranes, nose, eye, vagina, penis, skin
17	*Sporotrichum schenckii*	Sporotrichosis	Worldwide	Cat, cattle, dog, horse, mouse, mule, rat	Mine timbers, soil, plants	Hands, feet, cutaneous and subcutaneous tissue, lymphatics

/1/ Animals are often difficult or even impossible to infect because of the great variation in susceptibility. /3/ Not resembling many of the common yeasts.

Contributors: (a) Halde, Carlyn, (b) Georg, Lucille K., (c) Friedman, Lorraine

References: [1] Ainsworth, G. C. 1952. Medical mycology. Pitman, New York. [2] Ainsworth, G. C., and P. K. C. Public Health Serv. Publ. 994. [4] Conant, N. F., et al. 1954. Manual of clinical mycology. W. B. Saunders, 1963. Medical mycology. Lea and Febiger, Philadelphia. [7] Kaplan, W. 1959. J. Am. Vet. Med. Assoc. 134(3): et al. 1958. An introduction to medical mycology. Yearbook, Chicago. [10] Wilson, J. W. 1957. Clinical and

MYCOSES

Susceptible Laboratory Animals[1]	Microscopic Appearance: In Human Tissue	Microscopic Appearance: Of Culture at 25°C	Microscopic Appearance: Of Culture at 37°C	
(G)	(H)	(I)	(J)	
Mouse, rat	Spherical, single-budding, thick-walled cells, 5-20 μ, surrounded by wide gelatinous capsule	Similar to cells seen in tissue[a]; abortive hyphae may be seen on primary isolation	Similar to cells seen in tissue	8
None	Oblong-to-rectangular cells with somewhat rounded ends, 4-8 μ	Mycelium segments into rectangular arthrospores; germ tube forms at corners	Similar to growth at 25°C	9
Guinea pig, hamster, mouse	Intracellular, oval, budding cells, 1-5 μ	Delicate mycelium with thin-walled, subspherical-to-pyriform conidia, 2-5 μ, and thick-walled, tuberculated conidia, 8-20 μ	Budding cells, 1-5 μ; must be grown on enriched medium	10
Guinea pig, hamster, mouse	Intracellular, ovoid, budding cells, 7 x 15 μ (occasionally up to 80 μ); walls 1-2 μ thick; fat droplets	Identical to above	Budding cells, 5-15 μ	11
Guinea pig, mouse	Delicate, branched, gram-positive hyphae, 0.5-1 μ diameter; partially acid-fast	Branching hyphae, 0.5-1 μ diameter, break up readily into bacillary or coccoid forms	Similar to cultures at 25°C	12
Guinea pig, mouse	Granules of gram-positive, branching hyphae, 0.5-1 μ diameter	Branching hyphae, 0.5-1 μ diameter; spherical conidia, 0.5-1 μ, sparse to absent	Similar to cultures at 25°C	13
Guinea pig, hamster, mouse	Multiple-budding, thick-walled cells, 10-60 μ	Mycelium with rare oval conidia, 3-5 μ	Similar to forms observed in tissue	14
Mouse, rat	Single or clustered spherical, thick-walled, dark brown cells, 6-12 μ, multiply by splitting, not budding	Three types of sporulation: *Phialophora*--conidia borne within a terminal cuplike structure on a flask-shaped conidiophore; *Cladosporium*--conidia in branching chains arising terminally from conidiophore; *Acrotheca*--conidia borne acropleurogenously on swollen, clublike conidiophore	Similar to cultures at 25°C	15
None	Thick-walled spherule, 50-350 μ, with pore, containing up to 16,000 endospores, 7-9 μ	No culture method available	No culture method available	16
Hamster, mouse, rat	Rarely seen without special stains; gram-positive, cigar-shaped or spherical-to-oval, usually intracellular, budding cells, 3-5 μ; asteroid forms rare	Delicate hyphae, 2 μ in width, pyriform-to-spherical conidia, 2-4 x 2-6 μ, borne in clusters on lateral branches or laterally along hyphae	Cigar-shaped, spherical or oval budding cells; must be grown on enriched medium	17

truc of some strains which may be weakly encapsulated in vitro, giving culture a different gross appearance

Austwich. 1958. Commonwealth Agr. Bur. (Gt. Brit.) Animal Health Rev. Ser. 6. [3] Ajello, L., et al. 1963. U.S. Philadelphia. [5] Dodge, C. W. 1935. Medical mycology. C. V. Mosby, St. Louis. [6] Emmons, C. W., et al. 113-117. [8] Langeron, M., and R. Vanbruseghem. 1952. Précis de mycologie. G. Masson, Paris. [9] Lewis, G., immunologic aspects of fungus disease. C. C. Thomas, Springfield.

XIII. MATERIALS AND METHODS

140. CULTURE MEDIA: PROTOZOA

Part 1. PARASITIC AMOEBAE

	Medium (A)	Species Showing Growth (B)
	Bacteria[1]	
	Diphasic	
1	**Slant**: Coagulated whole egg. **Overlay**: Locke's, Ringer's or saline solution, alone or with one or more of the following: serum, egg white, rice (starch, flour, or powder).	*Dientamoeba fragilis* [24][2], [14][3]; *Endolimax nana* [11,24][2]; *Entamoeba aulostomi* [13][2]; *E. coli* [17][3], [23][4]; *E. gingivalis* [12][2]; *E. histolytica* [5, 11][2], [6][3]; *E. invadens* [15][2]; *Iodamoeba buetschlii* [24][2]
2	**Slant**: Coagulated serum. **Overlay**: Ringer's or saline solution with serum, egg white and rice.	*Endolimax nana, Entamoeba coli, E. gingivalis, E. histolytica* [11][2]; *E. invadens* [16][3]; *E. muris* [21][2]
3	**Slant**: Liver infusion agar. **Overlay**: Saline with serum and rice.	*Entamoeba histolytica* [7][2], [8][3]; *E. invadens* [22][2]
	Liquid	
4	Locke's, Ringer's, or saline solution with serum and rice.	*Endamoeba thomsoni* [27][2]; *Entamoeba barreti* [3][2]; *E. invadens* [22][2]; *E. ranarum* [4][2]
5	Egg infusion, rice starch, with or without liver extract.	*Dientamoeba fragilis* [2][2]; *Entamoeba coli* [2][2]; *E. histolytica* [1][2]; *E. invadens* [15, 18][2]; *E. terrapini* [18][2]
6	Fluid thioglycollate broth with serum[5].	*Entamoeba coli, E. histolytica* [25][3]
	Protozoa[1]	
7	Trypticase-dextrose broth with serum[6].	*Entamoeba histolytica* [20][3]; *E. invadens, E. terrapini* [9][3]
	Tissue[1]	
8	Saline, tissue slice.	*Entamoeba invadens* [19]
9	Hank's salt solution with serum and chick embryo (minced or sliced).	*Entamoeba histolytica* [26]
	Axenic Culture[7]	
	Diphasic	
10	**Slant**: Tryptose, trypticase, yeast extract agar with serum. **Overlay**: Tryptose, trypticase, yeast extract broth with cell-free chick embryo extracts and vitamins.	*Entamoeba histolytica* [10]
	Liquid	
11	Trypticase, yeast extract, maltose broth with serum.	*Entamoeba invadens, E. terrapini* [9]

/1/ Growth occurs in presence of one or more types of metabolizing cell: bacteria, protozoa, or metazoa. /2/ Xenic growth (unknown number of associates present in culture). /3/ Monoxenic growth (one associate present). /4/ Dixenic growth (two associates present). /5/ Preconditioned with a streptobacillus. /6/ Preconditioned with *Trypanosoma cruzi*. /7/ Growth occurs in absence of any other metabolizing cell.

Contributors: Diamond, Louis S., and Bartgis, I. Louise

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Part II. TRICHOMONADIDAE

	Medium (A)	Species Showing Growth[1] (B)
	Agnotobiotic Culture[2]	
1	Egg-yolk infusion: Medium, with or without liver extract, with rice starch, 1-10% serum enrichment. For preparation, consult reference 3.	Most species can be isolated and maintained in the presence of balanced contaminants.[3]
	Axenic Culture[4]	
2	Diamond's [6]: 2% trypticase, 1% yeast extract, 0.5% maltose, 0.1% L-cysteine HCl, 0.02% L-ascorbic acid, 0.08% KH_2PO_4, 0.08% K_2HPO_4, 0.05-0.10% agar, 10% inactivated sterile horse or sheep serum. Adjust to pH 6-8 with KOH, NaOH, or HCl (base or acid depends on species). Use with antibiotics for axenic isolation or retardation of bacterial growth. Autoclave 9 ml of medium 15 minutes at 15-lb pressure; add serum and antibiotics aseptically after medium has cooled. Use as soon as possible. Shelf-life 30 days at 4°C.	*Hypotrichomonas acosta*, *Monocercomonas* sp. (NS-1:PRR), *M. colubrorum*, *Trichomitis batrachorum*, *Tritrichomonas augusta* [24]; *Pentatrichomonas hominis*, *Tetratrichomonas gallinarum*, *Trichomonas gallinae*, *T. vaginalis*, *Tritrichomonas eberthi* [6]; *Tetratrichomonas buttreyi* [6, 9, 15]; *Trichomonas rotunda* [15]; *Tritrichomonas enteris* [1]; *T. foetus* [9]; *T. suis* [6, 15]
3	CPLM [21]: 3.0% bacto peptone, 0.1% agar, 0.2% cysteine HCl, 0.16% maltose, 20 ml/100 liver infusion, 65 ml/100 Ringer's solution, 10% sterile serum. Prepare as above. 0.002% methylene blue may be added as an indicator. 0.1% Wilson's gastric mucin 1701X stimulatory for *Trichomitis batrachorum* and *Tetratrichomonas prowazeki*.	*Hypotrichomonas acosta*, *Tritrichomonas augusta* [23]; *Pentatrichomonas hominis* [4, 41]; *Tetratrichomonas buttreyi*, *Trichomonas rotunda*, *Tritrichomonas suis* [15]; *Tetratrichomonas prowazeki* [17]; *Trichomitis batrachorum* [17]; *Trichomonas gallinae* [18]; *T. vaginalis* [21, 47]; *Tritrichomonas enteris* [1]; *T. foetus* [10]
4	B.B.L.[5] fluid thioglycollate[6]: With 5-10% sterile serum.	*Hypotrichomonas acosta* [23]; *Pentatrichomonas hominis*, *Trichomonas vaginalis* [5]; *Tetratrichomonas prowazeki* [17]; *Trichomonas gallinae* [18]
5	STS [22]: 2% trypticase, 0.15% cysteine HCl, 0.1% maltose, 0.1% agar, 5% sterile serum.	*Trichomonas vaginalis* [22]; *Tritrichomonas augusta* [34]
6	BMH [24]: 0.5% glucose, 1.0% trypticase, 0.25% yeast extract, 0.01% KH_2PO_4, 0.25% NA_2 glycerophosphate·5 H_2O, 0.004% Ca pantothenate, 0.005% cholesterol, 0.0001% TEM 4T, 0.1% agar, 0.04% ascorbic acid, 0.05% thiomalic acid, 0.004% trace-metals mixture #50, 1.0 ml/100 vitamin mixture #12. Grow newly inoculated cultures for 2 days at 25°C, then place at 15°C for 1-2 months.	*Hypotrichomonas acosta*, *Monocercomonas* sp. (NS-1:PRR), *M. colubrorum*, *Trichomitis batrachorum*, *Tritrichomonas augusta* [24]

/1/ Species isolated from homeotherms: *Pentatrichomonas hominis*, *Tetratrichomonas buttreyi*, *T. gallinarum*, *Trichomonas gallinae*, *T. tenax*, *T. vaginalis*, *Tritrichomonas eberthi*, *T. enteris*, *T. foetus*, *T. suis*. Species isolated from poikilotherms: *Hypotrichomonas acosta*, *Monocercomonas* sp. (NS-1:PRR), *M. colubrorum*, *Tetratrichomonas prowazeki*, *Trichomitis batrachorum*, *Tritrichomonas augusta*. /2/ Many media for parasitic amoeba also support agnotobiotic trichomonad cultures [44, 45] (*see* Part I). /3/ The following have been cultured agnotobiotically (in the presence of unknown other organisms): *Metatrichomonas termopsidis*, *Monocercomonas verrens*, *Tetratrichomonas limacis*, *T. microti*, *T. ovis*, *Trichomitis marmotae*. /4/ Because these media support high bacterial populations, antibiotics are necessary to retard bacterial overgrowth or for axenic isolation. The following antibiotic combinations have been successful for axenic isolation: 10,000 units/ml Na or K penicillin, 1,000 µg/ml streptomycin [6]; 2,000 µg/ml dehydrostreptomycin, 250 µg/ml chloroamphenicol, 60 µg/ml polymyxin B [23, 24]; for molds and yeasts, 300 µg/ml nystatin [16]; *see also* references 17, 38. /5/ Baltimore Biological Laboratory, Baltimore 18, Md. /6/ Or without indicator, Brewer-modified.

continued

Part II. TRICHOMONADIDAE

	Medium	Species Showing Growth[1]
	(A)	(B)
	Special Purpose	
7	Complex chemically better defined media [39]: Mixtures of salts, amino acids, nucleotides, lipids, trace metals, vitamins, and one or more poorly defined complex natural organic substances.	*Hypotrichomonas acosta* [23]; *Monocercomonas* sp. (NS-1:PRR), *M. colubrorum*, *Tritrichomonas augusta* [24]; *Trichomonas gallinae* [40]; *T. vaginalis* [42]
8	Complex medium for axenic *Trichomonas tenax*.	*Trichomonas tenax* [7]
9	Media and techniques for freezing cultures.	*Pentatrichomonas hominis* [8, 31]; *Trichomonas gallinae* [8, 19, 31]; *T. vaginalis* [8, 19, 32]; *Tritrichomonas foetus* [13, 14, 25-29, 31, 33]
10	Solid media for cloning and drug testing.	*Pentatrichomonas hominis*, *Tetratrichomonas gallinarum*, *Tritrichomonas augusta*, *T. suis* [35]; *Trichomonas gallinae* [2, 35]; *T. vaginalis* [12, 20, 35, 37]; *Tritrichomonas foetus* [35, 46]
11	Tissue culture.	*Trichomonas gallinae*, *T. vaginalis* [18]
12	Bulk growth or continuous flow culture.	*Pentatrichomonas hominis*, *Trichomonas vaginalis* [11, 30, 36]; *Tritrichomonas augusta* [36, 43]

/1/ Species isolated from homeotherms: *Pentatrichomonas hominis*, *Tetratrichomonas buttreyi*, *T. gallinarum*, *Trichomonas gallinae*, *T. tenax*, *T. vaginalis*, *Tritrichomonas eberthi*, *T. enteris*, *T. foetus*, *T. suis*. Species isolated from poikilotherms: *Hypotrichomonas acosta*, *Monocercomonas* sp. (NS-1:PRR), *M. colubrorum*, *Tetratrichomonas prowazeki*, *Trichomitis batrachorum*, *Tritrichomonas augusta*.

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continued

140. CULTURE MEDIA: PROTOZOA

Part III. TRYPANOSOMATIDAE

	Medium (A)	Species Showing Growth[1] (B)
	Blood Agar[2-5]	
1	**Solid phase**: 14 g agar, 6 g NaCl, 450 ml defibrinated rabbit blood, 900 ml distilled H_2O. For variation, consult reference 20.	*Leishmania enrietti* [4]; *L. donovani, L. tropica* [27]; *L. tarentolae* [42]; *Trypanosoma ambystomae* [16]; *T. brucei, T. lewisi* [20]; *T. cruzi, T. duttoni, T. melophagium, T. rotatorium, T. theileri*, 2 species of bird trypanosomes [30]; *T. striati* [32]
2	**Solid phase**: 10-15 g agar, 10 g glucose, 1,000 ml horse meat broth, 1,000 ml defibrinated horse blood.	*Crithidia melophagia, Leptomonas ctenocephali, L. fasciculata,* ~~*Trypanosoma cruzi,*~~ *T. rotatorium, T. syrnii, T. theileri* [28]; *Leishmania braziliensis* [33]; *L. donovani* [28, 33]; *L. tropica* [22, 33]; *Strigomonas oncopelti* [22]; *Trypanosoma conorhini* [7]
3	**Solid phase**: 50 g bacto beef, 20 g neopeptone, 5 g NaCl, 20 g bacto agar, 100-150 ml defibrinated human or rabbit blood. Variation: With Locke's solution overlay [14, 39][6].	*Leishmania braziliensis, L. donovani, L. tropica, Trypanosoma conorhini, T. lewisi, T. pipistrelli* [39]; *T. cruzi* [36, 39]; *T. rangeli* [38]
4	**Solid phase**: 31 g nutrient agar, 5 g plain agar, 167 ml inactivated human plasma, 167 ml washed human red cells.	*Trypanosoma gambiense, T. rhodesiense* [46]
5	**Solid phase**: 20 g agar, 5 g dextrose, 7 g NaCl, 20 g proteose peptone, 100 ml defibrinated rabbit blood. **Liquid phase**: Infusion broth containing 2% proteose peptone and 0.5% dextrose. For variation, consult reference 9.	*Trypanosoma cruzi* [6, 9]; *T. lewisi*, bird trypanosomes, frog trypanosomes [9]
6	**Solid phase**: 3 g bacto beef, 5 g bacto peptone, 8 g NaCl, 15 g bacto agar, 333 ml citrated human or rabbit blood. **Liquid phase**: Locke's solution.	*Trypanosoma congolense* [37]; *T. gambiense, T. rhodesiense* [41]
	Semi-Solid[3,4,7]	
7	1 part 3% agar, 8 parts Locke's solution with 0.2% glucose, 1 part rabbit serum.	*Herpetomonas muscidarum, Leishmania agamae, L. ceramodactyli, L. donovani, L. tarentolae, L. tropica, Strigomonas oncopelti, Trypanosoma cruzi, T. ptyodactyli, T. rabinowitschi* [1[illegible]
8	3 g agar, 150 ml defibrinated rabbit blood, 1,000 ml normal saline.	*Leishmania donov*[illegible]*ropica* [19]
9	Mixture of 21 amino acids, 3 salts, 10 vitamins, glucose, guanosine, adenine SO_4, uracil, uric acid, urea, creatine, creatinine, nucleic acid, 0.2% agar, heat-coagulated red blood cells.	*Trypanosoma cruzi* [17]
	Liquid[3,4,7]	
10	0.5 ml human or monkey blood, 0.5 ml 2% sodium citrate in 0.85% NaCl solution, 1 ml Ringer's solution (with 0.6% NaCl). For variation, consult reference 3.	*Trypanosoma brucei* [3]; *T. congolense, T. gambiense* [3, 34]; *T. cruzi* [34]
11	Overlay from item 3 for trypanosomes of the *lewisi* group and from item 6 for African trypanosomes.	*Trypanosoma congolense* [45]; *T. cruzi* [44]; *T. gambiense, T. rhodesiense* [41]
12	10 ml 5% lactoalbumin hydrolysate in Earle's saline, 5 ml filtered and unheated calf serum, 5 ml red cell lysate, 100 ml 0.1% glucose in Earle's saline.	*Trypanosoma gambiense* [26]
	Dialysate[3,7]	
13	Cellophane loop filled with Locke's solution suspended in tubes of diphasic blood agar. Variation: Loop suspended in blood-coagulum-peptone medium [10].	*Trypanosoma cruzi* [10, 40]
	Defined and Partially Defined[3,4,7]	
14	Mixture of amino acids, salts (including trace metals), glucose, purines, pyrimidines, vitamins, growth factors, and hemin. Variation: Only methionine as amino acid and no hemin [25].	*Herpetomonas culicidarum* [5]; *Leishmania tarentolae* [42]; *Strigomonas oncopelti* [25]

/1/ Use of the generic names *Crithidia, Herpetomonas, Leptomonas*, and *Strigomonas* is not yet uniform. /2/ Test-tube cultures usually contain 5 ml base; flask or plate cultures contain varying amounts of base, depending on size of container. /3/ Cultures usually maintained at 22°-25°C. /4/ Ingredients are given in amounts to be added to one liter of distilled water, unless otherwise specified. /5/ Diphasic test-tube cultures receive 2-3 ml overlay; flask cultures approximately 15 ml for each 25 ml base. /6/ 10% blood for *Trypanosoma cruzi* and *Leishmania* spp.; 30% for other species and all isolations. /7/ Varying amounts of media are used, depending on size of container.

continued

140. CULTURE MEDIA: PROTOZOA

Part III. TRYPANOSOMATIDAE

	Medium (A)	Species Showing Growth (B)
	Defined and Partially Defined[3,4,7]	
15	Item 9 without agar.	*Trypanosoma cruzi* [17]
16	15 g bacto tryptose, 2 g glucose, 1 mg thiamine, 3 mg folic acid, 20 mg hemin, 25 mg sodium stearate, 4 g NaCl, 5 g $Na_3PO_4 \cdot 12H_2O$, 0.4 g KCl, 1,000 ml twice-distilled H_2O.	*Trypanosoma cruzi* [2]
	Avian Embryo[8]	
17	Chorioallantoic membrane.	*Leishmania donovani, Trypanosoma gambiense* [35]; *Leishmania tropica* [29]; *Trypanosoma brucei, T. evansi* [18, 35]; *T. cruzi* [11, 31]; *T. equiperdum, T. rhodesiense* [18]
18	Intra-yolk sac.	*Leishmania braziliensis, L. donovani, L. tropica* [15]; *Trypanosoma brucei, T. equiperdum, T. evansi* [23]; *T. cruzi* [21]
	Tissue Culture[9]	
19	Mammalian tissues in nutrient fluid.	*Leishmania donovani* [13]; *Trypanosoma conorhini* [7]; *T. cruzi* [12, 31]; *T. gambiense, T. rhodesiense* [8]
20	Avian tissues in nutrient fluid.	*Trypanosoma cruzi* [24]
21	Insect tissues in nutrient fluid.	*Trypanosoma brucei, T. congolense, T. vivax* [43]

/3/ Cultures usually maintained at 22°-25°C. /4/ Ingredients are given in amounts to be added to one liter of distilled water, unless otherwise specified. /7/ Varying amounts of media are used, depending on size of container. /8/ Cultures usually maintained at 25°-35°C. /9/ Cultures usually maintained at 25°-38°C.

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Part IV. PHYTOMASTIGINA

	Constituent	Concentration mg/L[1]
	(A)	(B)
	Marine Flagellates[2] [8]	
1	Ca, as Cl	400
2	$MgCl_2 \cdot 6H_2O$	4,000
3	$MgSO_4 \cdot 7H_2O$	7,000
4	KCl	700
5	K_3PO_4	10
6	NaCl	28,000
7	$NaNO_3$	100
8	PII metals[3]	10 ml
9	SII metals[4]	10 ml
10	Sodium glycerophosphate	10
11	Sodium metasilicate $\cdot 9H_2O$	150
12	Nitrilotriacetic acid	100
13	Tris[5]	1,000
14	Biotin	1 µg
15	Cyanocobalamin	0.2 µg
16	Thiamine HCl	100 µg
17	pH = 7.8-8.0	
	***Chilomonas paramecium* [3]**	
18	NH_4Cl	200
19	H_3BO_3	115
20	$CaCl_2$	55
21	$CoSO_4 \cdot 7H_2O$	19
22	$CuSO_4 \cdot 5H_2O$	15.7
23	$FeSO_4 \cdot 7H_2O$	40
24	$MgSO_4 \cdot 7H_2O$	800
25	$MnSO_4 \cdot 4H_2O$	81
26	K_2HPO_4	200
27	$Na_2MoO_4 \cdot 2H_2O$	15
28	$ZnSO_4 \cdot 7H_2O$	220
29	EDTA[6]	500
30	Thiamine HCl	10 µg
31	pH = 3.5-7.5	
	***Chlamydomonas moewusii* [5]**	
32	B	20
33	Ca	50
34	Co	0.5
35	Cu	2
36	Fe	10
37	$MgSO_4 \cdot 7H_2O$	500
38	Mn	4
39	Mo	4
40	K_2HPO_4	250
41	Zn	20
42	Ammonium acetate	1,000
43	EDTA[6]	200
44	Glycine	2,000
45	pH = 7.5	
	***Chlorogonium* spp.[7] [6]**	
46	NH_4NO_3	500
47	$FeCl_3 \cdot 6H_2O$	2.5
48	$MgSO_4 \cdot 7H_2O$	100
49	$MnCl_2 \cdot 4H_2O$	0.1
50	KH_2PO_4	500
51	NaCl	100
52	pH = 7.0	
	***Euglena gracilis* [4]**	
53	B, as H_3BO_3	0.1
54	$CaCO_3$	80
55	Co, as SO_4	0.1
56	Cu, as SO_4	0.08
57	Fe, as SO_4	2
58	$MgSO_4 \cdot 7H_2O$	400
59	Mn, as SO_4	0.5
60	Mo, as $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	0.35
61	KH_2PO_4	300
62	V, as $Na_3VO_4 \cdot 16H_2O$	0.01
63	Zn, as SO_4	1
64	Ammonium succinate	600
65	Sucrose	15,000
66	DL-Malic acid	1,000
67	DL-Aspartic acid	2,000
68	L-Glutamic acid	3,000
69	Glycine	2,500
70	Cyanocobalamin	0.0002
71	Thiamine HCl	0.6
72	pH = 3-6	
	***Ochromonas* spp.[8] [1]**	
73	NH_4Cl	500[9]; 400[10]
74	B, as H_3BO_3	0.1
75	$CaCO_3$	50[9]; 150[10]
76	Co, as SO_4	0.1
77	Cu, as SO_4	0.08
78	Fe, as SO_4	2
79	$MgCO_3$ (basic)	400[9]; 500[10]
80	$MgSO_4 \cdot 7H_2O$	1,000[9]
81	Mn, as SO_4	0.5
82	Mo, as $(NH_4)_6Mo_7O_{24} \cdot H_2O$	0.35
83	KH_2PO_4	300
84	V, as $Na_3VO_4 \cdot 16H_2O$	0.01
85	Zn, as SO_4	1
86	Ammonium citrate	1,200[10]
87	Nitrilotriacetic acid	200[9]; 300[10]
88	Glucose	10,000
89	L-Arginine HCl	400[9]; 500[10]
90	L-Glutamic acid	10,000[9]; 3,000[10]
91	Glycine	100[9]
92	L-Histidine HCl	400[9]; 500[10]
93	DL-Methionine	600[10]
94	Biotin	10 µg[9]; 4 µg[10]
95	Cyanocobalamin	1 µg[10]
96	Thiamine HCl	1[9]; 2[10]
97	pH = 5.0	
	***Polytoma uvella*[11] [2]**	
98	NH_4Cl	500
99	H_3BO_3	120
100	$CaCl_2$	60

/1/ Unless otherwise specified. /2/ Chrysomonads, cryptomonads, dinoflagellates, and also diatoms. /3/ 1 ml of PII metals contains 1 mg ethylenediamine tetra-acetic acid, 0.01 mg Fe (as Cl), 0.2 mg B (as H_3BO_3), 0.04 mg Mn (as Cl), 0.005 mg Zn (as Cl), 0.001 mg Co (as Cl). /4/ 1 ml of SII metals contains 1.0 mg Br (as Na), 0.2 mg Sr (as Cl), 0.02 mg Rb (as Cl), 0.02 mg Li (as Cl), 0.001 mg I (as K), 0.05 mg Mo (as Na). /5/ Tris(hydroxymethyl)-aminomethane. /6/ Ethylenediamine tetra-acetic acid. /7/ *C. elongatum* and *C. euchlorum*. /8/ *O. danica* and *O. malhamensis*. /9/ *O. danica*. /10/ *O. malhamensis*. /11/ Other *Polytoma* species might grow in the same medium if thiamine HCl were added at 100 µg/L.

continued

140. CULTURE MEDIA: PROTOZOA

Part IV. PHYTOMASTIGINA

	Constituent	Concentration mg/L[1]
	(A)	(B)
	Polytoma uvella[11] [2]	
101	$CoSO_4 \cdot 7H_2O$	20
102	$CuSO_4 \cdot 5H_2O$	13
103	$FeSO_4 \cdot 7H_2O$	40
104	$MgSO_4 \cdot 7H_2O$	160
105	$MnSO_4 \cdot 4H_2O$	50
106	K_2HPO_4	40
107	$Na_2MoO_4 \cdot 7H_2O$	15
108	$ZnSO_4 \cdot 7H_2O$	220
109	Sodium acetate$\cdot 3H_2O$	2,720
110	EDTA[6]	100
111	Tris[5]	1,210
112	pH = 8.0	
	Polytomella caeca[12] [7]	
113	$MgSO_4 \cdot 7H_2O$	100
114	KH_2PO_4	500
115	NaCl	100
116	Ammonium acetate[13]	2,000
117	Thiamine	0.3-1.0
118	pH = 6.5	
	Synura spp.[14] [9]	
119	$(NH_4)_2SO_4$	60
120	Ca, as Cl	4
121	Fe, as Cl	0.5
122	Mg, as Cl	0.5
123	Mn, as Cl	0.01
124	K, as Cl	2
125	Sodium citrate$\cdot H_2O$	20
126	Sodium glycerophosphate$\cdot 5H_2O$	50
127	Sodium metasilicate$\cdot 9H_2O$	30
128	L-Histidine, free base	200
129	Cyanocobalamin	0.4 μg
130	pH = 6.0	

/1/ Unless otherwise specified. /5/ Tris(hydroxymethyl)aminomethane. /6/ Ethylenediamine tetra-acetic acid. /11/ Other *Polytoma* species might grow in the same medium if thiamine HCl is added at 100 μg/L. /12/ Sterilize medium, then add $CaCl_2$ and $FeC_6H_5O_7 \cdot 3H_2O$ sufficient to give a final concentration of 10 mg of each per liter. /13/ May be substituted with NH_4Cl and n-butanol (1 ml/L). /14/ *S. caroliniana* and *S. petersenii*.

Contributor: Provasoli, Luigi

References: [1] Aaronson, S., and H. Baker. 1959. J. Protozool. 6:282. [2] Cirillo, V. P. 1955. Proc. Soc. Exptl. Biol. Med. 88:352. [3] Holz, G. G. 1954. J.Protozool. 1:114. [4] Hutner, S. H., and M. K. Bach. 1955. Ibid. 3:101. [5] Hutner, S. H., et al. 1950. Proc. Am. Phil. Soc. 94:152. [6] Loefer, J. B. 1934. Biol. Bull. 66:1. [7] Lwoff, A. 1941. Ann. Inst. Pasteur 66:407. [8] Provasoli, L. 1961. In H. Iwasaki. Biol. Bull. 121:176. [9] Provasoli, L., and I. J. Pintner. 1960. Pymatuning Symp. Ecol. Publ. 2.

141. CULTURE MEDIA: ANIMAL TISSUES

Part I. BALANCED SALT SOLUTIONS

In general, these diluents are used only in combination with naturally occurring body substances (e.g., blood serum, tissue extracts), and/or with more complex, chemically defined, feeding solutions. pH of the final medium must be regulated. Inclusion of the names of commercial suppliers in no way implies endorsement by the Federation of American Societies for Experimental Biology.

	Constituent	Concentration mg/L
	(A)	(B)
	Ringer (mammalian) [9]	
1	$CaCl_2$	250
2	KCl	420
3	NaCl	9,000
	Ringer (amphibian) [8]	
4	$CaCl_2$	120
5	KCl	140
6	$NaHCO_3$	200
7	NaCl	6,500
	Locke[1] [6]	
8	$CaCl_2$	240
9	KCl	420
10	$NaHCO_3$	300
11	NaCl	9,000
12	Glucose	1,000
	Locke[1] [6]	
13	$CaCl_2$	200
14	KCl	200
15	$NaHCO_3$	200
16	NaCl	9,500
17	Glucose	1,000
	Tyrode[2,3] [10]	
18	$CaCl_2$	200
19	$MgCl_2 \cdot 6H_2O$	100[4]
20	KCl	200
21	$NaHCO_3$	1,000
22	NaCl	8,000
23	$NaH_2PO_4 \cdot H_2O$	50
24	Glucose	1,000

/1/ One of several solutions described by Locke. /2/ Available commercially from Colorado Serum Co., 4950 York Street, Denver 16, Colo. /3/ Available commercially from Difco Laboratories, 920 Henry Street, Detroit 1, Mich. /4/ Or may be 214 mg/L; degree of hydration not reported.

continued

141. CULTURE MEDIA: ANIMAL TISSUES

Part I. BALANCED SALT SOLUTIONS

	Constituent	Concentration mg/L
	(A)	(B)
	Gey (for tubes)[2,3,5-9] [3]	
25	$CaCl_2$	170
26	$MgCl_2 \cdot 6H_2O$	210
27	$MgSO_4 \cdot 7H_2O$	70
28	KCl	370
29	KH_2PO_4	30
30	$NaHCO_3$	2,270
31	NaCl	7,000
32	$Na_2HPO_4 \cdot 2H_2O$	150
33	Glucose	1,000
	Gey (for slides) [3]	
34	$CaCl_2$	170
35	$MgCl_2 \cdot 6H_2O$	210
36	$MgSO_4 \cdot 7H_2O$	70
37	KCl	370
38	KH_2PO_4	30
39	$NaHCO_3$	227
40	NaCl	8,000
41	$Na_2HPO_4 \cdot 2H_2O$	150
42	Glucose	1,000
	Earle[2,3,5-9] [2]	
43	$CaCl_2$	200
44	$MgSO_4$	100
45	KCl	400
46	$NaHCO_3$	2,200
47	NaCl	6,800
48	$NaH_2PO_4 \cdot H_2O$	140
49	Glucose	1,000
	Hanks[2,3,5-10] [4]	
50	$CaCl_2$	200
51	$MgSO_4 \cdot 7H_2O$	200
52	KCl	400
53	KH_2PO_4	100
54	$NaHCO_3$	1,273
55	NaCl	8,000
56	$Na_2HPO_4 \cdot 2H_2O$	100
57	Glucose	2,000
	Hanks[2,3,5-10] [5]	
58	$CaCl_2$	140
59	$MgSO_4 \cdot 7H_2O$	200
60	KCl	400
61	KH_2PO_4	60
62	$NaHCO_3$	350
63	NaCl	8,000
64	$Na_2HPO_4 \cdot 2H_2O$	60
65	Glucose	1,000
	Puck (Saline F)[2,8,9] [7]	
66	$CaCl_2 \cdot 2H_2O$	16
67	$MgSO_4 \cdot 7H_2O$	154
68	KCl	285
69	KH_2PO_4	83
70	$NaHCO_3$	1,200
71	NaCl	7,400
72	$Na_2HPO_4 \cdot 7H_2O$	290
73	Glucose	1,100
	Puck (Saline G)[2] [7]	
74	$CaCl_2 \cdot 2H_2O$	16
75	$MgSO_4 \cdot 7H_2O$	154
76	KCl	400
77	KH_2PO_4	150
78	$NaHCO_3$	0
79	NaCl	8,000
80	$Na_2HPO_4 \cdot 7H_2O$	290
81	Glucose	1,100
	Dulbecco[2,3] [1]	
82	$CaCl_2$	100
83	$MgCl_2 \cdot 6H_2O$	100
84	KCl	200
85	KH_2PO_4	200
86	NaCl	8,000
87	Na_2HPO_4	1,150

/2/ Available commercially from Colorado Serum Co., 4950 York Street, Denver 16, Colo. /3/ Available commercially from Difco Laboratories, 920 Henry Street, Detroit 1, Mich. /5/ Available commercially from Baltimore Biological Laboratory, Division of B-D Laboratories, Inc., 2201 Aisquith Street, Baltimore 18, Md. /6/ Available commercially from Flow Laboratories, Inc., 1710 Chapman Avenue, Rockville, Md. /7/ Available commercially from Grand Island Biological Co., 959 East River Road, Grand Island, N. Y. /8/ Available commercially from Hyland Laboratories, 4501 Colorado Boulevard, Los Angeles 39, Calif. /9/ Available commercially from Microbiological Associates, Inc., 4846 Bethesda Avenue, Bethesda 14, Md. /10/ One of two solutions described by Hanks.

Contributors: (a) Waymouth, Charity, (b) Ambrose, Charles Tesch

References: [1] Dulbecco, R., and M. Vogt. 1954. J. Exptl. Med. 99:167. [2] Earle, W. R. 1943. J. Natl. Cancer Inst. 4:165. [3] Gey, G. O., and M. K. Gey. 1936. Am. J. Cancer 27:55. [4] Hanks, J. H. 1948. J. Cellular Comp. Physiol. 31:235. [5] Hanks, J. H., and R. E. Wallace. 1949. Proc. Soc. Exptl. Biol. Med. 71:196. [6] Locke, F. S. 1901. Centr. Physiol. 14:670. [7] Puck, T. T., S. J. Cieciura, and A. Robinson. 1958. J. Exptl. Med. 108:945. [8] Ringer, S. 1883. J. Physiol. (London) 4:222. [9] Ringer, S. 1886. Ibid. 7:291. [10] Tyrode, M. V. 1910. Arch. Intern. Pharmacodyn. 20:205.

Part II. TISSUE CULTURE MEDIA

Inclusion of names of commercial suppliers in no way implies endorsement by the Federation of American Societies for Experimental Biology.

	Constituent	Concentration mg/L
	(A)	(B)
	Medium 199[1-7] [7]	
1	$CaCl_2$	200
2	$Fe(NO_3)_3 \cdot 9H_2O$	0.1
3	$MgSO_4 \cdot 7H_2O$	200
4	KCl	400
5	$NaHCO_3$	2,200
6	NaCl	6,800
7	$NaH_2PO_4 \cdot H_2O$	140
8	Sodium acetate	50.0
9	Glucose	1,000
10	2-Deoxy-D-ribose	0.5

continued

Part II. TISSUE CULTURE MEDIA

	Constituent (A)	Concentration mg/L (B)
	Medium 199[1-7] [7]	
11	D-Ribose	0.5
12	DL-Alanine	50.0
13	L-Arginine HCl	70.0
14	DL-Aspartic acid	60.0
15	L-Cysteine HCl	0.1
16	L-Cystine	20.0
17	DL-Glutamic acid	150.0
18	L-Glutamine	100.0
19	Glycine	50.0
20	L-Histidine HCl	20.0
21	Hydroxy-L-proline	10.0
22	DL-Isoleucine	40.0
23	DL-Leucine	120.0
24	L-Lysine HCl	70.0
25	DL-Methionine	30.0
26	DL-Phenylalanine	50.0
27	L-Proline	40.0
28	L-Serine	50.0
29	DL-Threonine	60.0
30	DL-Tryptophan	20.0
31	L-Tyrosine	40.0
32	DL-Valine	50.0
33	Adenosine triphosphate	10.0
34	Adenine	10.0
35	Guanine HCl	0.3
36	Hypoxanthine	0.3
37	Thymine	0.3
38	Uracil	0.3
39	Xanthine	0.3
40	Adenylic acid	0.2
41	Cholesterol	0.2
42	Tween 80	20.0
43	Glutathione	0.05
44	Vitamin A	0.1
45	*p*-Aminobenzoic acid	0.05
46	Ascorbic acid	0.05
47	Biotin	0.01
48	Calciferol	0.1
49	Choline HCl	0.50
50	Folic acid	0.01
51	*m*-Inositol	0.05
52	Menadione	0.01
53	Nicotinic acid	0.025
54	Nicotinamide	0.025
55	Ca pantothenate	0.01
56	Pyridoxal HCl	0.025
57	Pyridoxine HCl	0.025
58	Riboflavin	0.01
59	Thiamine HCl	0.01
60	α-Tocopherol phosphate	0.01
	CMRL 1066[1,3,7,8] [8]	
61	$CaCl_2$	200
62	$MgSO_4 \cdot 7H_2O$	200
63	KCl	400
64	$NaHCO_3$	2,200
65	NaCl	6,800
66	$NaH_2PO_4 \cdot H_2O$	140
67	Sodium acetate	83.0[9]
68	Sodium glucuronate	4.2
69	Glucose	1,000
70	L-Alanine	25.0
71	L-Arginine HCl	70.0
72	L-Aspartic acid	30.0
73	L-Cysteine HCl	260.0
74	L-Cystine	20.0
75	L-Glutamic acid	75.0
76	L-Glutamine	100.0
77	Glycine	50.0
78	L-Histidine HCl	20.0
79	Hydroxy-L-proline	10.0
80	L-Isoleucine	20.0
81	L-Leucine	60.0
82	L-Lysine HCl	70.0
83	L-Methionine	15.0
84	L-Phenylalanine	25.0
85	L-Proline	40.0
86	L-Serine	25.0
87	L-Threonine	30.0
88	L-Tryptophan	10.0
89	L-Tyrosine	40.0
90	L-Valine	25.0
91	Deoxyadenosine	10.0
92	Deoxycytidine HCl	10.0
93	Deoxyguanosine	10.0
94	5-Methyl deoxycytidine	0.1
95	Thymidine	10.0
96	Diphosphopyridine nucleotide	7.0
97	Flavin adenine dinucleotide	1.0
98	Triphosphopyridine nucleotide	1.0
99	Uridine triphosphate	1.0
100	Cocarboxylase	1.0
101	Coenzyme A	2.5
102	Cholesterol	0.2
103	Tween 80	5.0
104	Ethanol	16.0
105	Glutathione	10.0
106	*p*-Aminobenzoic acid	0.05
107	Ascorbic acid	50.0
108	Biotin	0.01
109	Choline HCl	0.50
110	Folic acid	0.01
111	*m*-Inositol	0.05
112	Nicotinic acid	0.025
113	Nicotinamide	0.025
114	Ca pantothenate	0.01
115	Pyridoxal HCl	0.025
116	Pyridoxine HCl	0.025
117	Riboflavin	0.01
118	Thiamine HCl	0.01
	Eagle's Basal[1-7] [1]	
119	$CaCl_2$	111
120	$MgCl_2$	102
121	KCl	373
122	$NaHCO_3$	1,680
123	NaCl	5,845
124	$NaH_2PO_4 \cdot H_2O$	138
125	Glucose	900
126	L-Arginine HCl	17.5
127	L-Cystine	12.0
128	L-Glutamine	292.0
129	L-Histidine HCl	7.75
130	L-Isoleucine	26.0
131	L-Leucine	26.0
132	L-Lysine HCl	29.0
133	L-Methionine	7.5
134	L-Phenylalanine	16.0
135	L-Threonine	24.0
136	L-Tryptophan	4.0
137	L-Tyrosine	18.0
138	L-Valine	23.0
139	Biotin	0.25
140	Choline HCl	0.14
141	Folic acid	0.44
142	Nicotinamide	0.12
143	Ca pantothenate	0.48
144	Pyridoxal HCl	0.20
145	Riboflavin	0.04
146	Thiamine HCl	0.34
147	Penicillin	50.0
148	Streptomycin	50.0
149	Phenol red	5.0
	Eagle's Minimum Essential[1,4-7] [2]	
150	$CaCl_2$	200
151	$MgCl_2 \cdot 6H_2O$	200
152	KCl	400
153	$NaHCO_3$	2,000
154	NaCl	6,800
155	$NaH_2PO_4 \cdot 2H_2O$	150
156	Glucose	1,000
157	L-Arginine HCl	105.0
158	L-Cystine	24.0
159	L-Glutamine	292.0
160	L-Histidine HCl	31.0
161	L-Isoleucine	52.0
162	L-Leucine	52.0
163	L-Lysine	58.0
164	L-Methionine	15.0
165	L-Phenylalanine	32.0
166	L-Threonine	48.0

/1/ Available commercially from Baltimore Biological Laboratory, Division of B-D Laboratories, Inc., 2201 Aisquith Street, Baltimore 18, Md. /2/ Available commercially from Colorado Serum Co., 4950 York Street, Denver 16, Colo. /3/ Available commercially from Difco Laboratories, 920 Henry Street, Detroit 1, Mich. /4/ Available commercially from Flow Laboratories, Inc., 1710 Chapman Ave., Rockville, Md. /5/ Available commercially from Grand Island Biological Co., 959 East River Road, Grand Island, N. Y. /6/ Available commercially from Hyland Laboratories, 4501 Colorado Boulevard, Los Angeles 39, Calif. /7/ Available commercially from Microbiological Associates, Inc., 4846 Bethesda Avenue, Bethesda 14. Md. /8/ Available commercially from Connaught Medical Research Laboratories, Toronto 4, Canada. /9/ For sodium acetate + $3H_2O$.

continued

Part II. TISSUE CULTURE MEDIA

	Constituent	Concentration mg/L
	(A)	(B)
	Eagle's Minimum Essential[1,4-7] [2]	
167	L-Tryptophan	10.0
168	L-Tyrosine	36.0
169	L-Valine	46.0
170	Choline HCl	1.0
171	Folic acid	1.0
172	*m*-Inositol	2.0
173	Nicotinamide	1.0
174	Ca pantothenate	1.0
175	Pyridoxal HCl	1.0
176	Riboflavin	0.1
177	Thiamine HCl	1.0
	NCTC 107[2,3] [4]	
178	$CaCl_2$	200
179	$MgSO_4 \cdot 7H_2O$	200
180	KCl	400
181	$NaHCO_3$	2,200
182	NaCl	6,800
183	$NaH_2PO_4 \cdot H_2O$	140
184	Sodium acetate	50.0
185	Sodium glucuronate	1.8
186	Glucose	1,000
187	Glucuronolactone	1.8
188	D-Glucosamine HCl	3.2
189	L-Alanine	31.48
190	L-α-Aminobutyric acid	5.51
191	L-Arginine HCl	25.76
192	L-Asparagine	8.09
193	L-Aspartic acid	9.91
194	L-Cysteine HCl	260.0
195	L-Cystine	10.49
196	L-Glutamic acid	8.26
197	L-Glutamine	135.73
198	Glycine	13.51
199	L-Histidine HCl	19.73
200	Hydroxy-L-proline	4.09
201	L-Isoleucine	18.04
202	L-Leucine	20.44
203	L-Lysine HCl	30.75
204	L-Methionine	4.44
205	L-Ornithine HCl	7.38
206	L-Phenylalanine	16.53
207	L-Proline	6.13
208	L-Serine	10.75
209	L-Taurine	4.18
210	L-Threonine	18.93
211	L-Tryptophan	17.50
212	L-Tyrosine	16.44
213	L-Valine	25.0
214	Deoxyadenosine	10.0
215	Deoxycytidine HCl	10.0
216	Deoxyguanosine	10.0
217	5-Methyl cytosine	0.1
218	Thymidine	10.0
219	Diphosphopyridine nucleotide	7.0
220	Flavin adenine dinucleotide	1.0
221	Triphosphopyridine nucleotide	1.0
222	Uridine triphosphate	1.0
223	Cocarboxylase	1.0
224	Coenzyme A	2.5
225	Cholesterol	2.0
226	Tween 80	22.5
227	Methyl linoleate	1.0
228	Methyl linolenate	1.0
229	Methyl arachidonate	1.0
230	Glutathione	10.1
231	Vitamin A	0.25
232	*p*-Aminobenzoic acid	0.125
233	Ascorbic acid	49.9
234	Biotin	0.025
235	Calciferol	0.25
236	Choline HCl	1.25
237	Folic acid	0.025
238	*m*-Inositol	0.125
239	Menedione	0.025
240	Nicotinic acid	0.0625
241	Nicotinamide	0.0625
242	Ca pentothenate	0.025
243	Pyridoxal HCl	0.0625
244	Pyridoxine HCl	0.0625
245	Riboflavin	0.025
246	Thiamine HCl	0.025
247	α-Tocopherol phosphate	0.025
248	Phenol red	20.0
	NCTC 109[3,4,6,7] [6]	
249	$CaCl_2$	200
250	$MgSO_4 \cdot 7H_2O$	100
251	KCl	400
252	$NaHCO_3$	2,200
253	NaCl	6,800
254	$NaH_2PO_4 \cdot H_2O$	140
255	Sodium acetate	50.0
256	Sodium glucuronate	1.8
257	Glucose	1,000
258	Glucuronolactone	1.8
259	D-Glucosamine HCl	3.2
260	L-Alanine	31.48
261	L-α-Aminobutyric acid	5.51
262	L-Arginine HCl	25.76
263	L-Asparagine	8.09
264	L-Aspartic acid	9.91
265	L-Cysteine HCl	260.0
266	L-Cystine	10.49
267	L-Glutamic acid	8.26
268	L-Glutamine	135.73
269	Glycine	13.51
270	L-Histidine HCl	19.73
271	Hydroxy-L-proline	4.09
272	L-Isoleucine	18.04
273	L-Leucine	20.44
274	L-Lysine HCl	30.75
275	L-Methionine	4.44
276	L-Ornithine HCl	7.38
277	L-Phenylalanine	16.53
278	L-Proline	6.13
279	L-Serine	10.75
280	L-Taurine	4.18
281	L-Threonine	18.93
282	L-Tryptophan	17.50
283	L-Tyrosine	16.44
284	L-Valine	25.0
285	Deoxyadenosine	10.0
286	Deoxycytidine	10.0
287	Deoxyguanosine	10.0
288	5-Methyl cytosine	0.1
289	Thymidine	10.0
290	Diphosphopyridine nucleotide	7.0
291	Flavin adenine dinucleotide	1.0
292	Triphosphopyridine nucleotide	1.0
293	Uridine triphosphate	1.0
294	Cocarboxylase	1.0
295	Coenzyme A	2.5
296	Tween 80	12.5
297	Glutathione	10.1
298	Vitamin A	0.25
299	*p*-Aminobenzoic acid	0.125
300	Ascorbic acid	49.9
301	Biotin	0.025
302	Calciferol	0.25
303	Choline HCl	1.25
304	Cyanocobalamin	1.0
305	Folic acid	0.025
306	*m*-Inositol	0.125
307	Menadione	0.025
308	Nicotinic acid	0.0625
309	Nicotinamide	0.0625
310	Ca pantothenate	0.025
311	Pyridoxal HCl	0.0625
312	Pyridoxine HCl	0.0625
313	Riboflavin	0.025
314	Thiamine HCl	0.025
315	α-Tocopherol phosphate	0.025
316	Phenol red	20.0
	NCTC 117 [3]	
317	$CaCl_2$	200
318	$MgSO_4 \cdot 7H_2O$	100
319	KCl	400
320	$NaHCO_3$	2,200
321	NaCl	6,800
322	$NaH_2PO_4 \cdot H_2O$	140
323	Sodium glucuronate	1.8
324	Glucose	1,000
325	Glucuronolactone	1.8
326	D-Glucosamine HCl	3.2
327	L-Alanine	31.48
328	L-α-Aminobutyric acid	5.51
329	L-Arginine HCl	25.76
330	L-Asparagine	8.09
331	L-Aspartic acid	9.91
332	L-Cysteine HCl	260.0
333	L-Cystine	10.49
334	L-Glutamic acid	8.26
335	L-Glutamine	135.73
336	Glycine	13.51
337	L-Histidine HCl	19.73
338	Hydroxy-L-proline	4.09
339	L-Isoleucine	18.04
340	L-Leucine	20.44
341	L-Lysine HCl	30.75
342	L-Methionine	4.44
343	L-Ornithine HCl	7.38

continued

Part II. TISSUE CULTURE MEDIA

	Constituent	Concentration mg/L
	(A)	(B)
	NCTC 117 [3]	
344	L-Phenylalanine	16.53
345	L-Proline	6.13
346	L-Serine	10.75
347	L-Taurine	4.18
348	L-Threonine	18.93
349	L-Tryptophan	17.50
350	L-Tyrosine	16.44
351	L-Valine	25.0
352	Deoxycytidine HCl	10.0
353	Thymidine	10.0
354	Tween 80	12.5
355	Glutathione	10.0
356	Vitamin A	0.25
357	*p*-Aminobutyric acid	0.125
358	Ascorbic acid	50.0
359	Biotin	0.025
360	Calciferol	0.25
361	Choline HCl	1.25
362	Cyanocobalamin	1.0
363	Folic acid	0.025
364	*m*-Inositol	0.125
365	Menadione	0.025
366	Nicotinic acid	0.0625
367	Nicotinamide	0.0625
368	Ca pantothenate	0.025
369	Pyridoxal HCl	0.0625
370	Pyridoxine HCl	0.0625
371	Riboflavin	0.025
372	Thiamine HCl	0.025
373	α-Tocopherol phosphate	0.025
374	Phenol red	20.0
	Puck's N16[2,3,5-7] [9]	
375	$CaCl_2 \cdot 2H_2O$	16
376	$MgSO_4 \cdot 7H_2O$	154
377	KCl	285
378	KH_2PO_4	83
379	$NaHCO_3$	1,200
380	NaCl	7,400
381	$Na_2HPO_4 \cdot 7H_2O$	290
382	Glucose	1,100
383	L-Arginine HCl	37.5
384	L-Aspartic acid	30.0
385	L-Cystine	7.5
386	L-Glutamic acid	75.0
387	L-Glutamine	200.0
388	Glycine	100.0
389	L-Histidine HCl	37.5
390	DL-Isoleucine	25.0
391	L-Leucine	25.0
392	L-Lysine HCl	80.0
393	L-Methionine	25.0
394	L-Phenylalanine	25.0
395	L-Proline	25.0
396	L-Threonine	37.5
397	L-Tryptophan	20.0
398	L-Tyrosine	40.0
399	DL-Valine	50.0
400	Hypoxanthine	25
401	Biotin	0.1
402	Choline HCl	3.0
403	Folic acid	0.1
404	*m*-Inositol	1.0
405	Nicotinamide	3.0
406	Ca pantothenate	3.0
407	Pyridoxine HCl	0.5
408	Riboflavin	0.5
409	Thiamine HCl	5.0
410	Phenol red	1.2
	Trowell's T8[6] [10]	
411	$CaCl_2$	220
412	$MgSO_4 \cdot 7H_2O$	250
413	KCl	450
414	$NaHCO_3$	2,820
415	NaCl	6,100
416	$NaH_2PO_4 \cdot 2H_2O$	450
417	Glucose	4,000
418	L-Arginine HCl	21.0
419	L-Cysteine HCl	47.0
420	L-Histidine HCl	10.0
421	L-Isoleucine	26.0
422	L-Leucine	26.0
423	L-Lysine HCl	36.0
424	DL-Methionine	15.0
425	L-Phenylalanine	33.0
426	L-Threonine	48.0
427	L-Tryptophan	4.0
428	L-Tyrosine	18.0
429	L-Valine	23.0
430	*p*-Aminobenzoic acid	35.0
431	Thiamine HCl	17.0
432	Insulin	50.0
433	Chloramphenicol	30.0
434	Phenol red	10.0
	MB 752/1[1,3,5-7] [11]	
435	$CaCl_2 \cdot 2H_2O$	120
436	$MgCl_2 \cdot 6H_2O$	240
437	$MgSO_4 \cdot 7H_2O$	200
438	KCl	150
439	KH_2PO_4	80
440	$NaHCO_3$	2,240
441	NaCl	6,000
442	Na_2HPO_4	300
443	Glucose	5,000
444	L-Arginine HCl	75.0
445	L-Aspartic acid	60.0
446	L-Cysteine HCl	90.0
447	L-Cystine	15.0
448	L-Glutamic acid	150.0
449	L-Glutamine	350.0
450	Glycine	50.0
451	L-Histidine HCl	150.0
452	L-Isoleucine	25.0
453	L-Leucine	50.0
454	L-Lysine HCl	240.0
455	L-Methionine	50.0
456	L-Phenylalanine	50.0
457	L-Proline	50.0
458	L-Threonine	75.0
459	L-Tryptophan	40.0
460	L-Tyrosine	40.0
461	L-Valine	65.0
462	Hypoxanthine	25
463	Glutathione	15.0
464	Ascorbic acid	17.5
465	Biotin	0.02
466	Choline HCl	250.0
467	Cyanocobalamin	0.2
468	Folic acid	0.4
469	*m*-Inositol	1.0
470	Nicotinamide	1.0
471	Ca pantothenate	1.0
472	Pyridoxine HCl	1.0
473	Riboflavin	1.0
474	Thiamine HCl	10.0
475	Phenol red	10.0
	MD 705/1 [5]	
476	$CaCl_2 \cdot 2H_2O$	120
477	$CoCl_2 \cdot 6H_2O$	0.11
478	$CuSO_4 \cdot 5H_2O$	0.25
479	$FeSO_4$	0.26
480	$MgCl_2 \cdot 6H_2O$	240
481	$MgSO_4 \cdot 7H_2O$	100
482	$MnSO_4 \cdot H_2O$	0.08
483	KCl	150
484	KH_2PO_4	80
485	$NaHCO_3$	2,240
486	NaCl	6,000
487	Na_2HPO_4	300
488	$ZnSO_4 \cdot 7H_2O$	0.15
489	Ammonium paramolybdate	0.12
490	Glucose	5,000
491	L-Arginine HCl	75.0
492	L-Aspartic acid	60.0
493	L-Cysteine HCl	90.0
494	L-Cystine	15.0
495	L-Glutamic acid	150.0
496	L-Glutamine	350.0
497	Glycine	50.0
498	L-Histidine HCl	150.0
499	L-Isoleucine	25.0
500	L-Leucine	50.0

/1/ Available commercially from Baltimore Biological Laboratory, Division of B-D Laboratories, Inc., 2201 Aisquith Street, Baltimore 18, Md. /2/ Available commercially from Colorado Serum Co., 4950 York Street, Denver 16, Colo. /3/ Available commercially from Difco Laboratories, 920 Henry Street, Detroit 1, Mich. /4/ Available commercially from Flow Laboratories, Inc., 1710 Chapman Ave., Rockville, Md. /5/ Available commercially from Grand Island Biological Co., 959 East River Road, Grand Island, New York. /6/ Available commercially from Hyland Laboratories, 4501 Colorado Boulevard, Los Angeles 39, Calif. /7/ Available commercially from Microbiological Associates, Inc., 4846 Bethesda Avenue, Bethesda 14, Md.

continued

141. CULTURE MEDIA: ANIMAL TISSUES

Part II. TISSUE CULTURE MEDIA

	Constituent (A)	Concentration mg/L (B)
	MD 705/1 [5]	
501	L-Lysine HCl	240.0
502	L-Methionine	50.0
503	L-Phenylalanine	50.0
504	L-Proline	50.0
505	L-Threonine	75.0
506	L-Tryptophan	40.0
507	L-Tyrosine	40.0
508	L-Valine	65.0
509	Hypoxanthine	25
510	Glutathione	15.0
511	Ascorbic acid	17.5
512	Biotin	0.02
513	Choline HCl	250.0
514	Cyanocobalamin	0.2
515	Folic acid	0.5
516	*m*-Inositol	1.0
517	Nicotinamide	1.0
518	Ca pantothenate	1.0
519	Pyridoxine HCl	1.0
520	Riboflavin	1.0
521	Thiamine HCl	10.0
522	Phenol red	10.0

Contributors: (a) Waymouth, Charity, (b) Parker, Raymond C.

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142. CULTURE MEDIA: PLANTS

Part I. BACTERIA

Amino acids given as DL-isomers.

	Constituent (A)	Concentration mg/L (B)
	Heterotrophic Bacteria[1,2]	
1	Peptone	5,000
2	Yeast extract	3,000
	Heterotrophic Bacteria[2,3]	
3	Peptone	5,000
4	Yeast extract	3,000
5	Agar	15,000
	Saprophytic *Actinomyces* and *Streptomyces*[4] [7]	
6	Glycerol	10,000
7	Asparagine	1,000
8	Dipotassium phosphate	1,000
9	Agar	15,000
	Photosynthetic Bacteria [4, 5]	
10	NH_4Cl	1,000
11	H_3BO_3	2.8
12	$CaCl_2$	100
13	$Co(NO_3)_2 \cdot 6H_2O$	0.05
14	$CuSO_4 \cdot 5H_2O$	0.02
15	$FeSO_4 \cdot 7H_2O$	20
16	$MgSO_4 \cdot 7H_2O$	250
17	$MnCl_2 \cdot 4H_2O$	0.05
18	K_2HPO_4	500
19	Na_2CO_3	2,000[5]
20	NaCl	3,000[6]
21	Na_2S	1,000[5]
22	$ZnSO_4 \cdot 7H_2O$	0.5
23	Potassium acetate	1,000[7]
24	Sodium succinate	4,000
25	Malic acid	3,000[7]
26	Glycerol	2,000[7]
27	Glutamic acid	2,000[7]
28	D-Biotin	0.004[7]
29	Niacin	1.0[7]
30	Thiamine HCl	1.0[7]
31	pH = 7-9	
	Bacillus subtilis [1]	
32	$(NH_4)_2HPO_4$	8,000
33	$FeCl_3 \cdot 6H_2O$	33
34	$MgSO_4 \cdot 7H_2O$	614
35	$MnSO_4$	15
36	KCl	400
37	NaCl	300
38	Na_2SO_4	4,000
39	$ZnCl_2$	10
40	Citric acid	2,000
41	Sucrose	100,000
42	Asparagine	2,000
43	Glutamic acid	2,000
44	Adenine sulfate	40
45	Guanine HCl	40
46	Uracil	40
47	Xanthine	40
48	*p*-Aminobenzoic acid	0.02
49	D-Biotin	0.02
50	Choline Cl	10
51	Folacin	0.02
52	L-Inositol	10
53	Niacin	2
54	DL-Ca pantothenate	4
55	Pyridoxine HCl	2

/1/ Nonsynthetic, nutrient broth prepared by adding specified ingredients to one liter of distilled water. /2/ Sugar broth or agar may be prepared by adding 5,000 mg/L of desired sugar. /3/ Nonsynthetic, nutrient agar prepared by adding specified ingredients to one liter of distilled water. /4/ Nonsynthetic medium prepared by adding specified ingredients to one liter of distilled water. /5/ For purple and green sulfur bacteria. /6/ For marine forms. /7/ For purple nonsulfur bacteria.

continued

142. CULTURE MEDIA: PLANTS

Part I. BACTERIA

	Constituent	Concentration mg/L
	(A)	(B)
	Bacillus subtilis [1]	
56	Pyridoxamine HCl	2
57	Riboflavin	4
58	Thiamine HCl	4
	Haemophilus parainfluenzae [2]	
59	$CaCl_2$	3
60	$FeSO_4 \cdot 7H_2O$	12.8
61	$MgSO_4 \cdot 7H_2O$	82
62	KH_2PO_4	3,120
63	Sodium acetate	6,000
64	Glucose	1,000
65	Alanine	1,000
66	Arginine HCl	400
67	Aspartic acid	1,000
68	Cystine	200
69	Glutamic acid	2,000
70	Glycine	100
71	Histidine HCl	200
72	Isoleucine	200
73	Leucine	200
74	Lysine HCl	400
75	Methionine	200
76	Phenylalanine	200
77	Proline	200
78	Serine	200
79	Threonine	200
80	Tryptophan	200
81	Tyrosine	200
82	Valine	200
83	Adenine sulfate	10
84	Guanine HCl	10
85	Uracil	10
86	Nicotinamide adenine dinucleotide	0.1
87	Putrescine	500
88	*p*-Aminobenzoic acid	0.001
89	D-Biotin	0.001
90	Choline Cl	5
91	Folacin	0.01
92	L-Inositol	20
93	Niacin	0.5
94	DL-Ca pantothenate	1
95	Pyridoxine HCl	2
96	Riboflavin	0.1
97	Thiamine HCl	1
	Lactobacillus leichmannii [6]	
98	NH_4Cl	280
99	$FeSO_4 \cdot 7H_2O$	10
100	$MgSO_4 \cdot 7H_2O$	1,400
101	$MnSO_4$	203
102	K_2HPO_4	2,000
103	KH_2PO_4	2,000
104	Sodium acetate	3,600
105	Sodium citrate	5,000
106	Sodium ethyl oxalacetate	100
107	Glucose	20,000
108	Alanine	200
109	Arginine HCl	200
110	Asparagine	200
111	Aspartic acid	200
112	Cysteine	800
113	Cystine	400
114	Glutamic acid	400
115	Glutamine	100
116	Glycine	300
117	Histidine HCl	200
118	Hydroxyproline	50
119	Isoleucine	300
120	Leucine	100
121	Lysine HCl	600
122	Methionine	100
123	Norleucine	200
124	Phenylalanine	500
125	Proline	400
126	Serine	100
127	Threonine	100
128	Tryptophan	50
129	Tyrosine	400
130	Valine	200
131	Adenine sulfate	5
132	Cytidylic acid	10
133	Guanine HCl	5
134	Uracil	5
135	Xanthine	8
136	Tween 80	1
137	*p*-Aminobenzoic acid	0.04
138	D-Biotin	0.005
139	Cyanocobalamin	0.01
140	Folacin	0.06
141	Niacin	1
142	DL-Ca pantothenate	1
143	Pyridoxal HCl	2
144	Pyridoxal phosphate	1
145	Pyridoxine HCl	2
146	Pyridoxamine HCl	0.4
147	Riboflavin	1
148	Thiamine HCl	1
149	pH = 5.5	
	Streptococcus faecalis [3]	
150	NH_4Cl	2,500
151	$FeSO_4 \cdot 7H_2O$	27
152	$MgSO_4 \cdot 7H_2O$	512
153	$MnSO_4$	30
154	K_2HPO_4	5,000
155	NaCl	15
156	Sodium acetate	5,000
157	Sodium citrate	5,000
158	Glucose	20,000
159	Alanine	500
160	Arginine HCl	400
161	Asparagine	500
162	Aspartic acid	500
163	Cystine	200
164	Glutamic acid	1,000
165	Glycine	100
166	Histidine HCl	200
167	Isoleucine	200
168	Leucine	200
169	Lysine HCl	400
170	Methionine	200
171	Phenylalanine	200
172	Proline	400
173	Serine	500
174	Threonine	200
175	Tryptophan	200
176	Tyrosine	200
177	Valine	200
178	Adenine sulfate	10
179	Uridine	0.2
180	Glutathione	20
181	Tween 80	10
182	*p*-Aminobenzoic acid	0.2
183	D-Biotin	0.01
184	Folacin	0.02
185	Niacin	1
186	DL-Ca pantothenate	0.5
187	Pyridoxine HCl	0.5
188	Pyridoxamine HCl	0.5
189	Riboflavin	0.5
190	Thiamine HCl	0.5

Contributors: (a) Pavcek, Paul L., (b) Clark, F. M., (c) Allen, Mary Belle

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continued

142. CULTURE MEDIA: PLANTS

Part II. FUNGI

	Constituent	Concentration mg/L[1]
	(A)	(B)
	Molds and Yeasts[2] [4]	
1	Potato extract[3]	1,000 ml
2	Glucose	10,000
3	Agar	15,000
	Molds and Yeasts[2,4] [5]	
4	Peptone	5,000
5	Yeast extract	3,000
6	Malt extract	3,000
7	Dextrose	10,000
8	Agar	20,000
	Aspergilli and Penicillia [3]	
9	$FeSO_4 \cdot 7H_2O$	10
10	$MgSO_4 \cdot 7H_2O$	500
11	KCl	500
12	K_2HPO_4	1,000
13	$NaNO_3$	3,000
14	Sucrose	30,000
15	pH = 6.8-6.9	
	***Neurospora* [1]**	
16	NH_4NO_3	1,000
17	H_3BO_3	0.06
18	$CaCl_2$	100
19	$CuSO_4 \cdot 5H_2O$	0.40
20	$FeSO_4 \cdot 7H_2O$	0.72
21	$MgSO_4 \cdot 7H_2O$	500
22	$MnCl_2 \cdot 4H_2O$	0.07
23	KH_2PO_4	1,000
24	NaCl	100
25	Na_2MoO_4	0.04
26	$ZnSO_4 \cdot 7H_2O$	8.8
27	Ammonium tartrate	5,000
28	Sucrose	15,000
29	D-Biotin	0.005
30	pH = 5.6	
	Basidiomycetes[5] [2]	
31	H_3BO_3	0.57
32	$CuSO_4 \cdot 5H_2O$	0.04
33	$FeSO_4 \cdot 7H_2O$	0.15
34	$MgSO_4 \cdot 7H_2O$	500
35	$MnCl_2 \cdot 4H_2O$	0.04
36	KH_2PO_4	1,500
37	$ZnSO_4 \cdot 7H_2O$	0.31
38	Ammonium para-molybdate	0.02
39	Glucose	10,000
40	L-Glutamic acid	1,200±[6]
41	Thiamine HCl	1
42	pH = 5.0-5.5	

/1/ Unless stated otherwise. /2/ Nonsynthetic medium. /3/ Boil 300 grams sliced potatoes for 20 minutes and strain through cotton. /4/ Prepared by adding specified ingredients to one liter of distilled water. /5/ Wood-rotting types. Biotin and/or riboflavin may be required by some species. /6/ Or DL-glutamic acid, 2,400± mg/L.

Contributors: (a) Clark, F. M., (b) Wolf, Frederick T., (c) Jennison, Marshall W.

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Part III. ALGAE

Variations of Pringsheim's soil-water medium are for nonsterile cultures, especially for isolation purposes and for growing algae to secure "normal" growth forms. Success with soil-water media depends on the selection of a suitable garden soil. This soil should be of medium humus content and should not have been recently fertilized with commercial fertilizers. Soils with a high clay content are usually not the most suitable for most organisms.
A variety of soil-water media can be made using a basic formula to which are added additional materials. The basic soil-water medium is made by placing one-quarter to one-half inch of garden soil in the bottom of a test tube, then adding pyrex-distilled water until the tube is three-quarters full. The tube is then plugged with cotton and steamed (not autoclaved) for one hour on two consecutive days. A few algae such as *Spirogyra* grow well in this basic medium. For most presumably phototrophic algae which thrive in an alkaline medium, a small pinch of powdered $CaCO_3$ is placed in the bottom of the test tube before the soil and water are added.
Some algae (*Astasia, Euglena, Polytoma, Polytomella, Pyrobotrys,* and others) require additional complex nitrogenous or carbon compounds not present in the basic formula. In the case of *Euglena* and *Pyrobotrys*, the best results have been obtained by adding one-quarter of a garden pea cotyledon to the basic medium (including $CaCO_3$) before steaming. For the colorless forms, the addition of a barley grain before steaming supplies the necessary carbon source. A few strains, such as *Botryococcus*, grow best when a pinch of sterile ammonium magnesium phosphate is added after the steaming of the basic medium (including $CaCO_3$). [3]

	Constituent	Concentration mg/L[1]
	(A)	(B)
	Marine Seaweeds [4]	
1	B, as H_3BO_3	2
2	Ca, as Cl	150
3	Co, as Cl	10 µg
4	Cu, as Cl	20 µg
5	Fe, as Cl	2
6	$MgSO_4 \cdot 7H_2O$	8,000
7	Mn, as Cl	1

/1/ Unless stated otherwise.

continued

142. CULTURE MEDIA: PLANTS

Part III. ALGAE

	Constituent	Concentration mg/L[1]
	(A)	(B)
	Marine Seaweeds [4]	
8	Mo, as Na salt	0.5
9	KCl	700
10	NaCl	24,000
11	$NaNO_3$	300
12	$Na_2SiO_3 \cdot 9H_2O$	70
13	Zn, as Cl	0.5
14	Potassium glycerophosphate	100
15	Sodium versenol	30
16	Tris[2]	1,000
17	Vitamin mix #8[3]	1 ml
18	Cyanocobalamin	0.5 µg
19	pH = 7.6	
	Cyanophyta [1]	
20	NH_4VO_3	0.02[4]
21	H_3BO_3	2.86
22	$CaCl_2$	55
23	$Co(NO_3)_2 \cdot 6H_2O$	0.05[4]
24	$CuSO_4 \cdot 5H_2O$	0.08
25	$FeSO_4 \cdot 7H_2O$	20
26	$MgSO_4 \cdot 7H_2O$	250
27	$MnCl_2 \cdot 4H_2O$	1.8
28	KNO_3	2,000[5]
29	K_2HPO_4	2,580
30	NaCl	40
31	Na_2CO_3	1,500[6]
32	Na_2MoO_4	0.2
33	$ZnSO_4 \cdot 7H_2O$	0.02
34	Sodium citrate	200
35	pH = 7-9	
	***Navicula pelliculosa* [2]**	
36	B	0.1
37	$Ca(NO_3)_2 \cdot 4H_2O$	1,000
38	Co	0.1
39	Cu	0.1
40	Fe	0.5
41	$MgSO_4 \cdot 7H_2O$	200
42	Mn	0.1
43	Mo	0.1
44	K_2HPO_4	200
45	Si, as orthosilicic acid	35
46	Zn	0.3
47	pH = 7.0-7.5	
	***Chlorella pyrenoidosa* [5]**	
48	B	0.5
49	Ca	0.5
50	Co[7]	0.01
51	Cu[7]	0.04
52	Fe[7]	0.2
53	$MgSO_4 \cdot 7H_2O$	500
54	Mn[7]	0.5
55	Mo	0.02
56	KH_2PO_4	1,310
57	V	0.01
58	Zn[7]	0.5
59	Urea[8]	440
60	pH = 6.0	

/1/ Unless stated otherwise. /2/ Tris(hydroxymethyl)aminomethane. /3/ 1 ml of vitamin mix #8 contains 0.2 mg thiamine HCl, 0.1 mg nicotinic acid, 0.04 mg putrescine·2HCl, 0.1 mg Ca pantothenate, 5.0 µg riboflavin, 0.04 mg pyridoxine·2HCl, 0.02 mg pyridoxamine·2HCl, 0.01 mg *p*-aminobenzoic acid, 0.5 µg biotin, 0.5 mg choline·H_2 citrate, 1.0 mg inositol, 0.8 mg thymine, 0.26 mg orotic acid, 0.05 µg cyanocobalamin, 0.2 µg folinic acid, 2.5 µg folic acid. /4/ Not yet shown to be generally required. /5/ May be omitted for nitrogen-fixing forms. /6/ For those strains which grow only at an alkaline pH. /7/ These metals were used as compounds chelated by ethylenediamine tetra-acetic acid. /8/ Or KNO_3, 1,440 mg/L.

Contributors: (a) Provasoli, Luigi, (b) Allen, Mary Belle, (c) Starr, Richard C.

References: [1] Allen, M. B., and D. I. Arnon. 1955. Plant Physiol. 30:366. [2] Lewin, J. C. 1955. Ibid. 30:129. [3] Pringsheim, E. G. 1950. In J. Brunel, ed. The culturing of algae. C. F. Kettering Foundation, Dayton. p. 19. [4] Provasoli, L., J. J. A. McLaughlin, and M. R. Droop. 1957. Arch. Mikrobiol. 25:408. [5] Sorokin, C., and R. W. Krauss. 1962. Plant Physiol. 37:37.

Part IV. HIGHER PLANTS

	Constituent	Concentration mg/L
	(A)	(B)
1	H_3BO_3	0.57
2	$Ca(NO_3)_2 \cdot 4H_2O$	1,180
3	$CuSO_4 \cdot 5H_2O$	0.04
4	$FeSO_4 \cdot 7H_2O$	2.5
5	$MgSO_4 \cdot 7H_2O$	493
6	$MnCl_2 \cdot 4H_2O$	0.90
7	H_2MoO_4	0.02
8	KH_2PO_4	136
9	K_2SO_4	349
10	$ZnSO_4 \cdot 7H_2O$	0.22

Contributor: Robbins, W. Rei

Reference: Robbins, W. R. Unpublished. Rutgers Univ., New Brunswick, N. J., 1963.

143. CULTURE MEDIA: PLANT TISSUES

Part I. BALANCED SALT SOLUTIONS

	Constituent	Concentration mg/L
	(A)	(B)
	White [3, 4]	
1	H_3BO_3	1.5
2	$Ca(NO_3)_2 \cdot 4H_2O$	300
3	$Fe_2(SO_4)_3$	2.5
4	$MgSO_4 \cdot 7H_2O$	720
5	$MnSO_4 \cdot 4H_2O$	7
6	KCl	65
7	KI	0.75
8	KNO_2	80
9	$NaH_2PO_4 \cdot H_2O$	16.5
10	$NaSO_4$	200
11	$ZnSO_4 \cdot 7H_2O$	3
	Heller [1, 2, 4]	
12	$AlCl_3$	0.03
13	H_3BO_3	1
14	$CaCl_2 \cdot 2H_2O$	75
15	$CuSO_4 \cdot 5H_2O$	0.03
16	$FeCl_3 \cdot 6H_2O$	1
17	$MgSO_4 \cdot 7H_2O$	250
18	$MnSO_4 \cdot 4H_2O$	0.1
19	$NiO_2 \cdot 6H_2O$	0.03
20	KCl	750
21	KI	0.01
22	$NaNO_3$	600
23	$NaH_2PO_4 \cdot H_2O$	125
24	$ZnSO_4 \cdot 7H_2O$	1

Contributor: White, Philip R.

References: [1] Gautheret, R. J. 1959. La culture des tissus végétaux. G. Masson, Paris. [2] Heller, R. 1953. Ann. Sci. Nat. Botan. Biol. Vegetale, Ser. 11, 14:1. [3] White, P. R. 1943. A handbook of plant tissue culture. J. Cattell Press, Lancaster, Penna. [4] White, P. R. 1963. The cultivation of animal and plant cells. Ed. 2. Ronald Press, New York.

Part II. TISSUE CULTURE MEDIA

	Constituent	Concentration mg/L
	(A)	(B)
	Stem Tips/1/ [1]	
1	Glucose	75,000
2	Agar	10,000
3	Gibberellin	1
	Root Tips/2/ [3, 4]	
4	Sucrose	20,000
5	Glycine	3
6	Niacin	0.5
7	Pyridoxine	0.1
8	Thiamine	0.1
	Callus/1/ [2, 4]	
9	Sucrose	50,000
10	Agar	5,000
11	Glycine	3
12	Niacin	0.5
13	Pyridoxine	0.1
14	Thiamine	0.1
15	2, 4-D	0.1
	Tumor/1/ [2, 4]	
16	Sucrose	50,000
17	Agar	5,000
18	Niacin	0.5
19	Pyridoxine	0.1
20	Thiamine	0.1

/1/ Add specified ingredients to either White's or Heller's balanced salt solution (*see* Part I). /2/ Add specified ingredients to White's balanced salt solution only (*see* Part I).

Contributor: White, Philip R.

References: [1] Ball, E. 1960. Growth 24:91. [2] Gautheret, R. J. 1959. La culture des tissus végétaux. G. Masson, Paris. [3] White, P. R. 1943. A handbook of plant tissue culture. J. Cattell Press, Lancaster, Penna. [4] White, P. R. 1963. The cultivation of animal and plant cells. Ed. 2. Ronald Press, New York.

144. NATURAL SEA WATER

Part I. GENERAL CHARACTERISTICS, SALINITY, AND CONSTITUENTS

Values are per kilogram of sea water, unless otherwise specified.

	Specification (A)	Value (B)
	General Characteristics	
1	Density	1.02-1.03
2	Temperature	-1.5 to +30°C
3	pH, surface water	8.1-8.3
4	pH, at depth	7.5-8.1
5	Freezing point[1]	-2°C
6	Specific heat[2]	0.955 cal/g
7	Velocity of sound	1,450-1,550 m/sec
8	Transparency, maximum[3]	66 m
9	Hydrostatic pressure[4]	1 atm/10 m
	Salinity	
10	All oceans, average	33-37 g
11	Below 1,000 m (-0.5 to +5°C)	34.6-35.0 g
12	At equator	35 g
13	20th-40th parallel, N. latitude	35.5 g
14	10th-30th parallel, S. latitude	35.5 g
15	Average, 60° N. and S. latitudes to Poles	35 g
16	North Pacific	34.5 g
17	North Sea, off Denmark	34 g
18	Indian Ocean, near Australia	35.5 g
19	South Pacific, off Peru	35.5 g
20	Arabian Sea	36-37 g
21	Sargasso Sea, N. Atlantic	36.5-37.0 g
22	South Atlantic, off Brazil	36-37 g
23	Red Sea (surface)	38-41 g
24	Mediterranean Sea (surface)	37-39 g
25	Gulf of Mexico (surface)	36-37 g
26	Antarctic Ocean (surface)	34.0-34.6 g
27	Arctic Ocean (surface)	32-33 g
	Constituents[5]	
28	Aluminum	0.5 mg
29	Argon[6]	0.4-0.7 mg
30	Arsenic	10-20 µg
31	Barium	54 µg
32	Bicarbonate	0.14 g
33	Bismuth	0.2 µg
34	Boric acid	26 mg
35	Boron	4.6 mg
36	Bromine	65 mg
37	Cadmium	Present
38	Calcium	0.40 g
39	Carbon	28 mg
40	Carbon dioxide[6]	64-107 mg
41	Cerium	0.4 µg
42	Cesium	2 µg
43	Chlorine	18.98 g
44	Chromium	Present
45	Cobalt	0.1 µg
46	Copper	1-10 µg
47	Fluorine	1.4 mg
48	Gallium	0.5 µg
49	Gold	0.006 µg
50	Helium and neon[6]	0.03 µg
51	Iodine	50 µg
52	Iron	2-20 µg
53	Lanthanum	0.3 µg
54	Lead	4 µg
55	Lithium	0.1 mg
56	Magnesium	1.27 g
57	Manganese	1-10 µg
58	Mercury	0.03 µg
59	Molybdenum	0.5 µg
60	Nickel	0.1 µg
61	Nitrogen[6]	10-18 mg
62	Nitrogen[7]	0.006-0.700 mg
63	Oxygen[6]	0-12 mg
64	Phosphorus	1-100 µg
65	Potassium	0.38 g
66	Radium	$0.2\text{-}3.0 \times 10^{-7}$ µg
67	Rubidium	0.2 mg
68	Scandium	0.04 µg
69	Selenium	4 µg
70	Silicon	0.02-4.00 mg
71	Silver	0.3 µg
72	Sodium	10.56 g
73	Strontium	13 mg
74	Sulfate	2.65 g
75	Sulfur	0.88 g
76	Thorium	0.4 µg
77	Tin	3 µg
78	Uranium	1.5 µg
79	Vanadium	0.3 µg
80	Yttrium	0.3 µg
81	Zinc	5 µg

/1/ For water with salinity of slightly more than 35 g/kg. /2/ For sea water with a salinity of 35 g/kg at 20°C and atmospheric pressure (760 mm Hg). /3/ Depth at which a 30-cm Secchi disk disappears from sight in the Sargasso Sea. /4/ Hydrostatic pressure increases approximately one atmosphere (760 mm Hg) for each ten meters of depth, the exact value being affected by salinity, temperature, and latitude. /5/ Based on total salinity of 34.325 g/kg, or standard chlorinity of 19 g/kg. /6/ As dissolved gas. /7/ In combined form.

Contributors: (a) Bowman, H. H. M., (b) Olson, F. C. W., (c) Redfield, Alfred C.

References: [1] Bowman, H. H. M. 1956. Ohio J. Sci. 56(2):101. [2] Bruns, E. 1962. Ozeanologie. Deutscher Verlag der Wissenschaften, Berlin. Bd. 2. [3] Marmer, H. A. 1930. The sea. D. Appleton, New York. [4] Olson, F. C. W. Unpublished. Radio Corp. of America, Princeton, N. J., 1963. [5] Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. 1942. The oceans. Prentice-Hall, New York.

continued

144. NATURAL SEA WATER

Part II. SURFACE TEMPERATURE OF THE OCEANS

Values are degrees centigrade.

	Latitude	Atlantic Ocean	Indian Ocean	Pacific Ocean
	(A)	(B)	(C)	(D)
	North			
1	70-60	5.60	.....	.....
2	60-50	8.66	.....	5.74
3	50-40	13.16	.....	9.99
4	40-30	20.40	.....	18.62
5	30-20	24.16	26.14	23.38
6	20-10	25.81	27.23	26.42
7	10-0	26.66	27.88	27.20
	South			
8	70-60	-1.30	-1.50	-1.30
9	60-50	1.76	1.63	5.00
10	50-40	8.68	8.67	11.16
11	40-30	16.90	17.00	16.98
12	30-20	21.20	22.53	21.53
13	20-10	23.16	25.85	25.11
14	10-0	25.18	27.41	26.01

Contributor: Sverdrup, H. U.

Reference: Sverdrup, H. U., M. W. Johnson, and R.H. Fleming. 1942. The oceans. Prentice-Hall, New York.

Part III. RELATION OF CHLORINITY AND SALINITY TO DENSITY

Chlorinity is defined as the amount, in grams, of precipitated halides (chlorine, bromine, and iodine), as determined by precipitation with a silver salt, in one kilogram of salt water. Salinity is defined as the total weight, in grams, of dissolved solids in one kilogram of sea water, when all carbonate has been converted to oxide, the bromine and iodine replaced by chlorine, and all organic matter completely oxidized. The standard chlorinity of sea water is 19, and equals a salinity of 34.325 (salinity = 0.03 + 1.805 x chlorinity).

	Chlorinity g/kg	Salinity g/kg	Density at 15°C g/cm³
	(A)	(B)	(C)
1	1	1.84	1.000578
2	2	3.64	1.001967
3	3	5.45	1.003354
4	4	7.25	1.004739
5	5	9.06	1.006123
6	6	10.86	1.007506
7	7	12.67	1.008888
8	8	14.47	1.010268
9	9	16.28	1.011649
10	10	18.08	1.013029
11	11	19.89	1.014409
12	12	21.69	1.015789
13	13	23.50	1.017169
14	14	25.30	1.018550
15	15	27.11	1.019932
16	16	28.91	1.021314
17	17	30.72	1.022698
18	18	32.52	1.024084
19	19	34.33	1.025471
20	20	36.13	1.026860
21	21	37.94	1.028251
22	22	39.74	1.029645
23	23	41.54	1.031041

Contributor: Olson, F. C. W.

Reference: Japan Meteorological Agency. 1955. Oceanographical tables. Tokyo.

Part IV. OXYGEN SATURATION FROM NORMAL DRY ATMOSPHERE

Oxygen saturation values may be 3% too high.

	Chlorinity g/kg	Salinity g/kg	Oxygen Saturation in ml/L[1] at -2°C	0°C	5°C	10°C	15°C	20°C	25°C	30°C
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
1	15	27.11	9.01	8.55	7.56	6.77	6.14	5.63	5.17	4.74
2	16	28.91	8.89	8.43	7.46	6.69	6.07	5.56	5.12	4.68
3	17	30.72	8.76	8.32	7.36	6.60	6.00	5.50	5.06	4.63
4	18	32.52	8.64	8.20	7.26	6.52	5.93	5.44	5.00	4.58

/1/ Milligram-atoms of oxygen per liter = 0.08931 x ml/L.

continued

144. NATURAL SEA WATER

Part IV. OXYGEN SATURATION FROM NORMAL DRY ATMOSPHERE

	Chlorinity g/kg	Salinity g/kg	Oxygen Saturation in ml/L[1] at -2°C	0°C	5°C	10°C	15°C	20°C	25°C	30°C
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
5	19	34.33	8.52	8.08	7.16	6.44	5.86	5.38	4.95	4.52
6	20	36.11	8.39	7.97	7.07	6.35	5.79	5.31	4.86	4.46

/1/ Milligram-atoms of oxygen per liter = 0.08931 x ml/L.

Contributor: Sverdrup, H. U.

Reference: Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. 1942. The oceans. Prentice-Hall, New York.

Part V. PRESSURE - DEPTH GRADIENT

Hydrostatic pressure increases approximately one atmosphere (760 mm Hg) for each ten meters of depth, the exact value being affected by salinity, temperature, and latitude.

	Depth meters	Salinity g/kg	Temp. °C	Latitude 30° atm/meter	Latitude 60° atm/meter
	(A)	(B)	(C)	(D)	(E)
1	0	32	0	0.099141	0.099403
2	0	32	20	0.098831	0.099092
3	0	35	0	0.099375	0.099638
4	0	35	20	0.099052	0.099314
5	5000	35	0	0.101757	0.102026
6	5000	35	5	0.101660	0.101929
7	10,000	35	0	0.103952	0.104225

Contributor: ZoBell, Claude E.

Reference: Bjerknes, V. F. K., and J. W. Sandström. 1910. Carnegie Inst. Wash. Publ. 88.

145. ARTIFICIAL SEA WATER

	Salt	Concentration mg/L
	(A)	(B)
	Brujewicz [4]	
1	$CaCl_2$	1,141
2	$MgCl_2$	2,447
3	$MgSO_4$	3,305
4	KCl	725
5	$NaHCO_3$	202
6	NaBr	83
7	NaCl	26,518
	TOTAL	34,421
	Lyman and Fleming [11]	
8	H_3BO_3	26
9	$CaCl_2$	1,102
10	$MgCl_2$	4,981
11	KBr	96
12	KCl	664
13	$NaHCO_3$	194
14	NaCl	23,277
15	NaF	3
16	Na_2SO_4	3,917
17	$SrCl_2$	24
	TOTAL	34,284
	Allen and Nelson [2]	
18	$CaCl_2$	510
19	$MgCl_2$	3,420
20	$MgSO_4$	2,100
21	KCl	750
22	NaCl	26,750
	TOTAL	33,530
	ZoBell [17]	
23	NH_4NO_3	2
24	H_3BO_3	27
25	$CaCl_2$	1,140
26	$FePO_4$	1
27	$MgCl_2$	5,143
28	KBr	100
29	KCl	690
30	$NaHCO_3$	200
31	NaCl	24,320
32	NaF	3
33	Na_2SiO_3	2
34	Na_2SO_4	4,060
35	$SrCl_2$	26
	TOTAL	35,714
	Robertson and Webb [15]	
36	$CaCl_2$	1,117
37	$MgCl_2$	4,978
38	KCl	725
39	NaCl	23,465
40	Na_2SO_4	3,928
	TOTAL	34,213
	Allen [1]	
41	$CaCl_2$	1,200
42	$MgCl_2$	2,550
43	$MgSO_4$	3,500
44	KCl	770
45	$NaHCO_3$	250
46	NaCl	28,130
	TOTAL	36,400
	Levring [9]	
47	$CaCl_2$	1,180
48	$MgCl_2$	2,540
49	$MgSO_4$	3,482
50	KCl	770
51	$NaHCO_3$	200

continued

	Salt	Concentration mg/L
	(A)	(B)
	Levring [9]	
52	$NaCl$	28,320
53	$NaNO_3$	100
54	Na_2HPO_4	10
	TOTAL	36,602
	Fowler and Allen [7]	
55	$CaCl_3$	100
56	$CaSO_4$	1,300
57	$MgBr_2$	100
58	$MgCl_2$	3,800
59	$MgSO_4$	1,600
60	K_2SO_4	900
61	$NaCl$	27,200
	TOTAL	35,000
	Lewin[1] [10]	
62	$Ca(NO_3)_2$	68
63	$MgCl_2$	5,000
64	K_2HPO_4	20
65	$NaHCO_3$	200
66	$NaCl$	23,000
67	Na_2SO_4	4,000
	TOTAL	32,288
	Harvey [8]	
68	$Ca(NO_3)_2$	678
69	$FeCl_3$	25
70	$MgSO_4$	2,439
71	KCl	600
72	K_2HPO_4	20
73	$NaCl$	30,000
	TOTAL	33,762
	McClendon-Gault-Mulholland [12]	
74	Al_2Cl_6	13
75	NH_3	2
76	H_3BO_3	58
77	$CaCl_2$	1,153
78	$LiNO_3$	1.3
79	$MgCl_2$	2,260
80	$MgSO_4$	3,248
81	H_3PO_4	0.2
82	KCl	721
83	$NaHCO_3$	198
84	$NaBr$	58
85	$NaCl$	26,726
86	Na_2SiO_3	2.4
87	$Na_2Si_4O_9$	1.5
	TOTAL	34,442.4
	Chu [6]	
88	$Al_2(SO_4)_3$	3
89	As_2O_3	0.03
90	$BaCl_2$	0.077
91	H_3BO_3	26
92	$CaCl_2$	1,102
93	$CuSO_4$	0.036
94	$FeC_6H_5O_7$	0.54
95	$LiNO_3$	1.1
96	$MgCl_2$	4,981
97	$MnCl_2$	0.2
98	KBr	96
99	KCl	664
100	KI	0.06
101	$RbHCO_3$	0.34
102	$NaHCO_3$	192
103	$NaCl$	23,476
104	NaF	3
105	$NaNO_3$	50
106	Na_2HPO_4	5
107	Na_2SiO_3	4.3
108	Na_2SO_4	3,917
109	$SrCl_2$	24
110	$ZnSO_4$	0.005
	TOTAL	34,545.69
	Rice [14]	
111	$MgCl_2$	1,171
112	$MgSO_4$	1,612
113	$MnCl_2$	2
114	KCl	700
115	KNO_3	100
116	KH_2PO_4	7.5
117	$NaHCO_3$	200
118	$NaCl$	26,500
119	Na_2SiO_3	10
120	$ZnSO_4$	0.005
	TOTAL	30,302.51
	Vishniac[2] [16]	
121	$(NH_4)_2CO_3$	200
122	H_3BO_3	1.2
123	$CaCl_3$	200
124	$CoSO_4$	0.2
125	$FeCl_3$	2
126	$MgCl_2$	1,000
127	$MgSO_4$	2,439
128	$MnSO_4$	6
129	KH_2PO_4	100
130	$NaCl$	25,000
131	Na_2MoO_4	0.2
132	$ZnSO_4$	5
133	EDTA[3]	500
	TOTAL	29,453.6
	McElroy and Farghaly[4] [13]	
134	NH_4NO_3	1,000
135	$FeCl_3$	0.0288
136	$MgSO_4$	100
137	$MnSO_4$	0.0012
138	KH_2PO_4	700
139	$NaCl$	30,000
140	Na_2HPO_4	1,784
	TOTAL	33,584.03
	Bernhard [3]	
141	$Al_2(SO_4)_3$	0.0247
142	As_2O_3	0.03
143	H_3BO_3	15
144	$CaCl_2$	1,180
145	$CoSO_4$	0.0048
146	$CuSO_4$	0.0004
147	$FeCl_3$	6.2929
148	$FeC_6H_5O_7$	5
149	$LiNO_3$	0.9935
150	$MgCl_2$	2,540
151	$MgSO_4$	3,482
152	$MnCl_2$	0.0036
153	$NiCl_2$	0.0041
154	KBr	9.679
155	KCl	770
156	KI	0.0785
157	$RbHCO_3$	0.0343
158	$NaHCO_3$	200
159	$NaCl$	28,320
160	NaF	3
161	$NaNO_3$	100
162	Na_2HPO_4	10
163	$SrCl_2$	1.826
164	$ZnSO_4$	0.022
	TOTAL	36,643.99

/1/ Enriched with trace elements [5]. /2/ Iron (0.2 mg) supplied by the following stock culture: 24.9 mg/ml $FeSO_4 \cdot 7H_2O$, 30 mg/ml EDTA, and 20 mg/ml $(NH_4)_2CO_3$. /3/ Ethylenediamine tetra-acetic acid. /4/ Trace elements included by preparing one liter of the following solution, then adding 0.05 ml to one liter of culture medium: 2.7 g $CaCl_2$, 0.96 g $FeCl_3 \cdot 6H_2O$, 36 mg $MnSO_4 \cdot 4H_2O$, and 39 mg $CuSO_4 \cdot 5H_2O$. Ten mg L-histidine and 10 mg DL-threonine added to improve luminescence. Ten ml glycerol also added.

Contributor: Jones, Galen E.

References: [1] Allen, E. J. 1914. J. Marine Biol. Assoc. U. K. 10:417. [2] Allen, E. J., and E. W. Nelson. 1907. Ibid. 8:42. [3] Bernhard, M. 1957. Pubbl. Staz. Zool. Napoli 29:80. [4] Brujewicz, S. W. 1931. In N. N. Subow, et al., ed. Oceanographical tables. Oceanographical Institute, Hydro-Meteorological Committee of USSR, Moscow. p. 146. [5] Burkholder, P. R., and L. G. Nickell. 1949. Botan. Gaz. 110:426. [6] Chu, S. P. 1949. Sci. Technol. China 2(3):38. [7] Fowler, G. H., and E. J. Allen. 1928. Science of the sea. Clarendon Press, Oxford. p. 68. [8] Harvey, G. W. Unpublished. Scripps Institution of Oceanography, La Jolla, Calif.

continued

145. ARTIFICIAL SEA WATER

[9] Levring, T. 1946. Fysiograf. Saellskap. 16(7):1. [10] Lewin, R. A. 1955. Can. J. Botany 33:5. [11] Lyman, J., and R. H. Fleming. 1940. J. Marine Res. (Sears Found. Marine Res.) 3:134. [12] McClendon, J. F., C. C. Gault, and S. Mulholland. 1917. Carnegie Inst. Wash. Publ. 251. [13] McElroy, W. D., and A.H. Farghaly. 1948. Arch. Biochem. 17(3):379. [14] Rice, T. R. 1956. Limnol. Oceanog. 1(2):123. [15] Robertson, J. D., and D. A. Webb. 1939. J. Exptl. Biol. 16:155. [16] Vishniac, H. S. 1955. Trans. N. Y. Acad. Sci. 17:352. [17] ZoBell, C. E. 1946. Marine microbiology. Chronica Botanica, Waltham, Mass. p. 21.

146. NORMAL SOLUTIONS

To prepare a 0.1 *N* solution, add the specified number of grams of the compound to 1,000 milliliters of solvent.

	Compound	Formula	Grams
	(A)	(B)	(C)
1	Ammonium molybdate	$(NH_4)_2MoO_4$	9.79
2	Ammonium oxalate	$(NH_4)C_2O_4$	10.6
3	Barium chloride	$BaCl_2$	12.2
4	Copper sulfate	$CuSO_4$	12.5
5	Ferric chloride	$FeCl_3$	5.4
6	Hydrobromic acid	HBr	8.1
7	Hydrochloric acid[1]	HCl	3.65
8	Potassium dichromate	$K_2Cr_2O_7$	4.90
9	Potassium hydroxide	KOH	5.6
10	Potassium permanganate	$KMnO_4$	3.16
11	Potassium thiocyanate	KSCN	9.71
12	Silver nitrate	$AgNO_3$	16.9
13	Sodium chloride	NaCl	5.9
14	Sodium hydroxide	NaOH	4.0
15	Sodium sulfide	Na_2S	3.90
16	Sodium thiosulfate	$Na_2S_2O_3$	24.80
17	Strontium chloride	$SrCl_2$	7.93
18	Sulfuric acid[1]	H_2SO_4	9.80
19	Zinc nitrate	$Zn(NO_3)_2$	9.47

/1/ Concentrated.

Contributor: Carleton, Ralph K.

References: [1] Benedetti-Pichler, A. A. 1942. Introduction to the microtechnique of inorganic analysis. J. Wiley, New York. [2] Charlot, G., and R. C. Murray. 1954. Qualitative inorganic analysis. Ed. 4. J. Wiley, New York. [3] Feigl, F., and R. E. Oesper. 1954. Spot tests in organic analysis. Ed. 6. Elsevier, Amsterdam. [4] Fritz, J. S., and G. S. Hammond. 1957. Quantitative organic analysis. J. Wiley, New York. [5] Heisig, G. B. 1950. Theory and practice of semimicro qualitative analysis. Ed. 2. W. B. Saunders, Philadelphia. [6] Milton, R. F., and W. A. Waters. 1955. Methods of quantitative micro-analysis. Ed. 2. St. Martins, New York. [7] Reedy, J. H. 1938. Elementary qualitative analysis for college students. McGraw-Hill, New York. [8] Rieman, W., J. D. Neuss, and B. Naiman. 1942. Quantitative analysis. Ed. 2. McGraw-Hill, New York. [9] Sandell, E. B. 1959. Colorimetric determination of traces of metals. Ed. 3. Interscience, New York. [10] Scott, W. W., ed. 1938. Standard methods of chemical analysis. Ed. 5. Van Nostrand, New York. [11] Snell, F. D., and C. T. Snell. 1959. Colorimetric methods of analysis. Ed. 3. Van Nostrand, New York. v. 2A. [12] Vogel, A. I. 1961. A textbook of quantitative inorganic analysis. Ed. 3. Longmans, Green; London. [13] Vosburgh, W. C. 1938. Introductory qualitative analysis. Macmillan, New York. [14] Welcher, F. J. 1947-48. Organic analytical reagents. Van Nostrand, New York. [15] Young, R. S. 1953. Industrial inorganic analysis. J. Wiley, New York.

147. BUFFER SOLUTIONS: pH RANGES

	Acidic Component	Alkaline Component	pH Range
	(A)	(B)	(C)
1	Hydrochloric acid	Glycine	1.0-3.7
2	Hydrochloric acid	Potassium hydrogen phthalate	2.2-4.0
3	Citric acid	Disodium hydrogen phosphate	2.2-8.0
4	Acetic acid	Sodium acetate	3.7-5.6

continued

147. BUFFER SOLUTIONS: pH RANGES

	Acidic Component	Alkaline Component	pH Range
	(A)	(B)	(C)
5	Potassium hydrogen phthalate	Sodium hydroxide	4.0-6.2
6	Potassium dihydrogen phosphate	Sodium hydroxide	5.8-8.0
7	Hydrochloric acid	Tris(hydroxymethyl)aminomethane	7.0-9.0
8	Diethylbarbituric acid	Sodium diethylbarbiturate	7.0-9.2
9	Hydrochloric acid or boric acid	Borax	8.0-9.2
10	Glycine	Sodium hydroxide	8.2-10.1
11	Borax	Sodium hydroxide	9.2-11.0
12	Sodium bicarbonate	Sodium hydroxide	9.6-11.0
13	Disodium hydrogen phosphate	Sodium hydroxide	11.0-12.0

Contributor: Bates, Roger G.

References: [1] Bates, R. G., and V. E. Bower. 1956. Anal. Chem. 28:1322. [2] Bower, V. E., and R. G. Bates. 1955. J. Res. Natl. Bur. Std. 55:197. [3] Clark, W. M. 1928. The determination of hydrogen ions. Ed. 3. Williams and Wilkins, Baltimore. p. 192. [4] Clark, W. M., and H. A. Lubs. 1916. J. Biol. Chem. 25:479. [5] Cohn, E. J., F. F. Heyroth, and M. F. Menkin. 1928. J. Am. Chem. Soc. 50:696. [6] McIlvaine, T. C. 1921. J. Biol. Chem. 49:183. [7] Sørensen, S. P. L. 1912. Ergeb. Physiol. 12:393.

148. WEAK ACIDS AND BASES: pK VALUES

pK values (dissociation constants) were determined at 25°C. pK values quoted for bases are for the *acidic* dissociation process. Thus the pK value 9.245, given for ammonia, corresponds to the dissociation $NH_4^+ \rightarrow H^+ + NH_3$. The *basic* dissociation constant, corresponding to the dissociation $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$, is 4.752 (13.997 minus 9.245), where 13.997 is the dissociation constant of water at 25°C.

	Acid or Base	pK
	(A)	(B)
1	Acetic acid	4.756
2	Alanine	pK_1 2.348; pK_2 9.866
3	*p*-Aminobenzoic acid	pK_1 2.413; pK_2 4.853
4	Ammonia	9.245
5	Aniline	4.603
6	Ascorbic acid	4.25
7	Benzoic acid	4.201
8	Boric acid	9.234
9	Carbonic acid	pK_1 6.352; pK_2 10.329
10	Chloroacetic acid	2.865
11	Citric acid	pK_1 3.128; pK_2 4.761; pK_3 6.396
12	Diethylbarbituric acid	7.980
13	Dihydroxytartaric acid	pK_1 1.947; pK_2 4.004
14	Ethylenediamine	pK_1 6.838; pK_2 9.960
15	Formic acid	3.752
16	Fumaric acid	pK_1 3.019; pK_2 4.384
17	Glucose-1-phosphoric acid	pK_2 6.503
18	Glycine	pK_1 2.350; pK_2 9.780
19	Glycolic acid	3.831
20	Histidine	pK_1 1.82; pK_2 6.00; pK_3 9.17
21	Hydrocyanic acid	9.22
22	Hydrofluoric acid	3.17
23	Hydrogen sulfide	7.06
24	Hydroxylamine	5.96
25	Iodic acid	0.775
26	Isonicotinic acid	pK_1 1.84; pK_2 4.86
27	Lactic acid	3.860
28	Maleic acid	pK_1 1.921; pK_2 6.225
29	Malonic acid	pK_1 2.847; pK_2 5.696
30	Methylamine	10.624
31	Nicotinic acid	pK_1 2.07; pK_2 4.81
32	*p*-Nitrophenol	7.156
33	Oxalic acid	pK_1 1.271; pK_2 4.266
34	Oxaloacetic acid	pK_1 2.555; pK_2 4.370
35	Phenol	9.998
36	Phenylacetic acid	4.307
37	Phosphoric acid	pK_1 2.148; pK_2 7.198; pK_3 12.375
38	*o*-Phthalic acid	pK_1 2.950; pK_2 5.408
39	Proline	pK_1 1.952; pK_2 10.640
40	Propionic acid	4.874
41	Pyridine	5.22
42	Pyrrolidine	11.305
43	Pyruvic acid	2.490
44	Salicylic acid	pK_1 2.996; pK_2 13.59
45	Succinic acid	pK_1 4.207; pK_2 5.638
46	Sulfuric acid	pK_2 1.983
47	Sulfurous acid	pK_1 1.76; pK_2 7.20
48	Tartaric acid	pK_1 3.033; pK_2 4.366
49	Tartronic acid	pK_1 2.366; pK_2 4.735
50	Tris(hydroxymethyl)-aminomethane	8.075

Contributor: Robinson, R. A.

Reference: Robinson, R. A., and R. H. Stokes. 1959. Electrolyte solutions. Ed. 2. Butterworth, London.

149. ACID - BASE INDICATORS: pH RANGES

A solution containing 0.1% indicator is generally satisfactory. Although some of the indicators are water-soluble, 70-90% ethanol is recommended as the solvent for most.

	Indicator	pH Range	Acid Color	Basic Color
	(A)	(B)	(C)	(D)
1	Methyl violet 6B	0.1-1.5	Yellow	Blue
2	Thymol blue (acid range)	1.2-2.8	Red	Yellow
3	Tropaeolin 00	1.4-3.2	Red	Yellow
4	Dimethyl yellow	2.8-4.0	Red	Yellow
5	Methyl orange	3.1-4.4	Red	Yellow
6	Bromphenol blue	3.2-4.6	Yellow	Blue
7	Bromcresol green	3.8-5.4	Yellow	Blue
8	Methyl red	4.2-6.2	Red	Yellow
9	Chlorphenol red	5.0-6.8	Yellow	Red
10	Bromcresol purple	5.2-6.8	Yellow	Purple
11	Bromthymol blue	6.0-7.6	Yellow	Blue
12	Phenol red	6.6-8.2	Yellow	Red
13	Neutral red	6.8-8.0	Red	Yellow
14	Cresol red	7.2-8.8	Yellow	Red
15	Thymol blue (alk. range)	8.0-9.6	Yellow	Blue
16	Phenolphthalein	8.2-10.0	Colorless	Pink
17	Thymolphthalein	9.4-10.6	Colorless	Blue
18	Alizarin yellow R	10.2-12.0	Yellow	Red
19	Nitramine	10.8-12.8	Colorless	Orange-brown
20	Trapaeolin 0	11.2-12.8	Yellow	Orange-brown
21	1, 3, 5-Trinitrobenzene	12.0-14.0	Colorless	Orange

Contributor: ZoBell, Claude E.

References: [1] Britton, H. T. S. 1956. Hydrogen ions. Ed. 4. Chapman, London. [2] Clark, W. M. 1928. Determination of hydrogen ions. Williams and Wilkins, Baltimore. [3] Clark, W. M., and H. A. Lubs. 1917. J. Bacteriol. 2(1):191. [4] Conn, H. J. 1961. Biological stains. Williams and Wilkins, Baltimore. [5] Gold, V. 1956. pH measurements. Methuen, London. [6] Kolthoff, I. M., and C. Rosenblum. 1937. Acid-base indicators. Macmillan, New York.

150. OXIDATION - REDUCTION INDICATORS

Redox potential (E_0') values are for varying pH at 30°C. Asterisk (*) denotes that indicator is unstable at designated pH.

	Indicator	E_0' (volts) at pH 5.0	pH 6.0	pH 7.0	pH 8.0	pH 9.0
	(A)	(B)	(C)	(D)	(E)	(F)
1	*m*-Bromophenol indophenol	+0.374	+0.311	+0.248	+0.179	+0.102
2	*o*-Chlorophenol indophenol	*	+0.301	+0.233	+0.155	+0.082
3	Phenol indophenol	*	+0.286	+0.227	+0.155	+0.083
4	Phenol blue	+0.365	+0.290	+0.224	+0.163	+0.091
5	2, 6-Dichlorophenol indophenol	+0.366	+0.295	+0.217	+0.150	+0.089
6	*m*-Cresol indophenol	*	+0.272	+0.208	+0.148	+0.076
7	*o*-Cresol indophenol	*	+0.256	+0.191	+0.130	+0.057
8	Thymol indophenol	*	+0.233	+0.174	+0.110	+0.041
9	*m*-Toluylenediamine indophenol	+0.195	+0.157	+0.125	+0.088	+0.037
10	Toluylene blue	+0.221	+0.162	+0.115	+0.082	+0.051
11	Thionine (Lauth's violet)	+0.138	+0.094	+0.062	+0.030	-0.001
12	Cresyl blue	+0.149	+0.089	+0.047	+0.015	-0.016
13	Gallocyanine	*	+0.080	+0.021	-0.037	-0.095
14	Methylene blue	+0.101	+0.047	+0.011	-0.020	-0.050
15	Toluidine blue	+0.087	+0.042	-0.005	-0.047	-0.099
16	Janus green (blue-red)	+0.050	+0.002	-0.035	-0.080	-0.115
17	Indigo tetrasulphonate	+0.065	+0.006	-0.046	-0.083	-0.114
18	Methyl capri blue	+0.038	-0.021	-0.060	-0.093	-0.123
19	Indigo trisulphonate	+0.032	-0.028	-0.081	-0.121	-0.152
20	Indigo disulphonate	+0.010	-0.069	-0.125	-0.167	-0.199
21	Gallophenine	-0.003	-0.077	-0.142	-0.202	-0.263
22	Brilliant alizarine blue	-0.040	-0.112	-0.173	-0.226	-0.279
23	Phenosafranine	-0.159	-0.219	-0.252	-0.283	-0.313
24	Tetramethyl phenosafranine	-0.156	-0.225	-0.273	-0.305	-0.336
25	Safranine T	-0.198	-0.250	-0.289	-0.318	-0.348
26	Neutral red	-0.204	-0.275	-0.325	-0.380	-0.435
27	Rosindone sulphonate No. 6	-0.287	-0.338	-0.385	-0.441	-0.508
28	Hydrogen electrode (theoretical)	-0.300	-0.361	-0.421	-0.481	-0.541

continued

150. OXIDATION - REDUCTION INDICATORS

Contributor: ZoBell, Claude E.

References: [1] Clark, W. M. 1925. Chem. Rev. 2:127. [2] Clark, W. M., et al. 1928. U. S. Hyg. Lab. Bull. 151. [3] Cohen, B., and M. Phillips. 1929. Public Health Rept. (U.S.), Suppl. 74. [4] Cohen, B., and P. W. Preisler. 1931. Ibid., Suppl. 92. [5] Hewitt, L. F. 1950. Oxidation-reduction potentials in bacteriology and biochemistry. E. and S. Livingstone, Edinburgh. [6] Michaelis, L., and L. B. Flexner. 1930. Oxidation-reduction potentials. J. B. Lippincott, Philadelphia. [7] Whitehead, T. H., and C. C. Wills. 1941. Chem. Rev. 29:69. [8] ZoBell, C. E. 1946. Bull. Am. Assoc. Petrol. Geol. 30(4):477.

151. RADIONUCLIDES USED IN BIOLOGICAL RESEARCH

Type (column D): α = alpha particle, a positively charged particle emitted by radioactive atomic nuclei at high speed, and having a mass number 4 and atomic number 2; β = beta particle, an electron, negative (β^- = negatron) or positive (β^+ = positron), emitted from the nucleus during radioactive disintegration; γ = gamma ray, electromagnetic radiation of short wavelength and correspondingly high frequency, emitted by the nucleus of an atom in the course of radioactive decay; ϵ = orbital electron capture, radioactive transformation occurring when a bound electron merges with the nucleus, converting a proton to a neutron, with liberation of energy in the form of a monoenergetic neutrino plus a photon of X ray characteristic of the new substance (it is a type of beta decay).

	Radionuclide			Radiation Emitted	
	Z[1]	Symbol and Mass No.	Half-Life[2]	Type	Energies, Mev[3] (% Disintegration)[4]
	(A)	(B)	(C)	(D)	(E)
1	1	H^{3}	12.26 yr	β^-	0.02(100)
2	6	C^{11}	20.4 min	β^+	0.97(100)
3	6	C^{14}	5,770 yr	β^-	0.16(100)
4	11	Na^{22}	2.6 yr	β^+	0.54(90)
5				ϵ	0.001(**10**)
6				γ	1.28(100)
7	11	Na^{24}	15 hr	β^-	1.39(100)
8				γ	2.75(100), 1.37(100)
9	15	P^{32}	14.2 da	β^-	1.71(100)
10	16	S^{35}	87.1 da	β^-	0.17(100)
11	17	Cl^{36}	3 x 10^5 yr	β^-	0.71(98)
12				ϵ	0.002(**2**)
13	17	Cl^{38}	37.3 min	β^-	4.81(53), 2.77(16), 1.11(31)
14				γ	2.15(57), 1.60(43)
15	19	K^{42}	12.4 hr	β^-	3.54(81), 1.98(18)
16				γ	1.53(18)
17	20	Ca^{45}	164 da	β^-	0.25(100)
18	24	Cr^{51}	27.8 da	ϵ	0.0049(**100**)
19				γ	0.32(10)
20	25	Mn^{52}	5.7 da	β^+	0.58(33)
21				ϵ	0.0054(**65**)
22				γ	1.45(100), 0.94(100), 0.73(100)
23	25	Mn^{54}	320 da	ϵ	0.0054(**100**)
24				γ	0.84(100)
25	26	Fe^{55}	2.7 yr	ϵ	0.0059(**100**)
26	26	Fe^{59}	45 da	β^-	0.46(53), 0.27(46), 0.13(1)
27				γ	1.29(43), 1.10(57), 0.19(3)
28	27	Co^{57}	270 da	ϵ	0.0064(**100**)
29				γ	0.14(6), 0.12(92), 0.01(9)
30	27	Co^{58}	71 da	β^+	0.47(15)
31				ϵ	0.0064(**85**)
32				γ	0.81(100)
33	27	Co^{60}	5.2 yr	β^-	0.31(100)
34				γ	1.33(100), 1.17(100)
35	29	Cu^{64}	12.8 hr	β^-	0.57(38)
36				β^+	0.66(19)
37				ϵ	0.0075(**42**)
38				γ	1.34(1)
39	30	Zn^{65}	244 da	β^+	0.32(2)
40				ϵ	0.008(**98**)
41				γ	1.11(49)
42	31	Ga^{72}	14.3 hr	β^-	3.17(5), 2.5(5), 1.94(7), 1.51(7), 0.96(35), 0.68(24), 0.66(17)
43				γ	2.51(19), 2.49(11), 2.20(32), 1.86(6), 1.68(2), 1.60(6), 1.46(4), 1.27(2), 1.23(1), 1.05(7), 0.89(11), 0.84(96), 0.81(3), 0.73(4), 0.63(23), 0.60(8), 0.44(1)
44	33	As^{76}	26.5 hr	β^-	2.97(55), 2.41(32), 1.76(4), 1.20(7), 0.56(1), 0.33(1),
45				γ	2.06(1), 1.22(6), 0.65(7), 0.56(5), 0.55(40)
46	35	Br^{82}	35.7 hr	β^-	0.44(100)
47				γ	1.47(17), 1.32(27), 1.04(28), 0.83(25), 0.78(83), 0.70(28), 0.62(42), 0.55(75), 0.35(3), 0.25(6)
48	37	Rb^{86}	18.7 da	β^-	0.70(10), 1.78(90)
49				γ	1.08(10)
50	38	Sr^{89}	54 da	β^-	1.46(100)
51	38	Sr^{90}	28 yr	β^-	0.54(100)
52	39	Y^{90}	64 hr	β^-	2.23(100)
53	47	Ag^{111}	7.5 da	β^-	1.06(93), 0.81(1), 0.73(6)
54				γ	0.34(6), 0.25(1)
55	49	In^{113m}	1.7 hr	γ	0.39(65)

/1/ Z = atomic number. /2/ Time required for the amount of a radioactive nuclide to decay to half its initial value. /3/ Mev = million electron volts. /4/ Values in boldface indicate percent of nuclear transmutations caused by electron capture.

continued

151. RADIONUCLIDES USED IN BIOLOGICAL RESEARCH

	Radionuclide			Radiation Emitted	
	Z[1]	Symbol and Mass No.	Half-Life[2]	Type	Energies, Mev[3] (% Disintegration)[4]
	(A)	(B)	(C)	(D)	(E)
56	50	Sn^{113}[5]	118 da	ϵ	**0.024(100)**
57				γ	0.26(2)
58	51	Sb^{124}	60 da	β^-	2.31(23), 1.66(2), 1.59(7), 0.95(6), 0.61(51), 0.22(11)
59				γ	2.11(7), 1.61(46), 1.45(2), 1.37(11), 1.33(2), 1.05(2), 0.97(3), 0.72(14), 0.64(7), 0.60(98)
60	52	Te^{121}	17 da	ϵ	**0.026(100)**
61				γ	0.58(87), 0.51(13), 0.07(2)
62	53	I^{125}	60 da	ϵ	**0.027(100)**
63				γ	0.04(7)
64	53	I^{130}	12.6 hr	β^-	1.02(46), 0.60(54)
65				γ	1.15(31), 0.74(69), 0.66(100), 0.53(100), 0.41(23)
66	53	I^{131}	8.05 da	β^-	0.81(1), 0.61(87), 0.34(9), 0.25(3)
67				γ	0.72(3), 0.64(9), 0.51(1), 0.36(80), 0.28(5), 0.08(2)
68	53	I^{132}	2.33 hr	β^-	2.12(18), 1.53(24), 1.16(23), 1.0(20), 0.7(15)
69				γ	2.2(2), 1.9(4), 1.40(13), 1.16(10), 0.96(23), 0.78(94), 0.67(100), 0.62(6), 0.53(28)
70	55	Cs^{134}	2.2 yr	β^-	0.89(1), 0.65(75), 0.28(3), 0.09(20)
71				γ	1.37(3), 1.31(1), 1.17(3), 0.80(8), 0.79(85), 0.60(97), 0.57(10), 0.56(12), 0.47(2), 0.20(10)
72	55	Cs^{137}[6]	30 yr	β^-	1.8(8), 0.51(92)
73	56	Ba^{137m}	2.6 min	γ	0.66(81)
74	79	Au^{198}	2.69 da	β^-	0.96(99), 0.28(1)
75				γ	0.68(1), 0.41(95)
76	80	Hg	2.7 da	ϵ	**0.068(100)**
77				γ	0.08(19)
78	80	Hg^{203}	47 da	β^-	0.21(100)
79				γ	0.28(81)
80	88	Ra^{226}[7]	1,620 yr	α, β^-, γ	Many

/1/ Z = atomic number. /2/ Time required for the amount of a radioactive nuclide to decay to half its initial value. /3/ Mev = million electron volts. /4/ Values in boldface indicate percent of nuclear transmutations caused by electron capture. /5/ Decays to In^{113m}. /6/ Decays to Ba^{137m}. /7/ In equilibrium with its gamma-emitting decay products.

Contributors: (a) Kahn, Bernd, (b) Siri, William E., (c) Way, Katharine

References: [1] Slack, L., and K. Way. 1959. Radiations from radioactive atoms in frequent use. U.S. Atomic Energy Commission, Washington, D. C. [2] Strominger, D., J. M. Hollander, and G. T. Seaborg. 1958. Rev. Mod. Phys. 30:585. [3] U.S. National Bureau of Standards. 1961. Handbook 80. U.S. Govt. Printing Office, Washington, D. C.

152. ANESTHETICS

Dose and Route (column C): iv = intravenous; rec = rectal; po = oral; ip = intraperitoneal; im = intramuscular.

	Drug	Animal	Dose and Route	Time to Act min	Duration	Remarks	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
	Mammalia[1]						
1	Anavenol-K	Sheep and other ungulates	10 ml/50 kg (about 20 mg/kg); iv[2]	....	20 min	Inject at 1 ml/sec[3]	16
2	Avertin	Cat	300 mg/kg as a 2.5% solution; rec	10	24 hr	Long duration due to lengthy recovery	17
3		Dog	500 mg/kg as a 2.5% solution; rec	....	......	....	17
4		Chipmunk	6.02 g/lb; po	1	3.5 hr	Lowers respiratory rate	13
5		Opossum	0.11 g/lb; po	6	10+ hr	....	13

/1/ For information on additional species, consult reference 12. /2/ Injection of additional half-dose ten minutes later prolongs action. /3/ Spinal block occurs; visual and auditory function persists.

continued

152. ANESTHETICS

	Drug	Animal	Dose and Route	Time to Act min	Duration	Remarks	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
			Mammalia[1]				
6	Nembutal	Small mammals	1/8-1/2 g/lb; iv[4]	....	15 min	Death due to shock is a general hazard; recovery long and violent	17
7		Ferret	1 gr in 1 ml at 0.45 gr/500 g body wt; ip	....	30 min	0.6-1.0 gr is dangerous dose	17
8		Fox, rabbit, raccoon, squirrel	1 gr/lb; ip	....	......	No ill effects	14
9		Mouse	1/25-1/50 gr for 15-20 g mouse; ip	6-15	1-5 hr	1 g in 10 ml water	8
10		Rat	3-5 mg/100 g in 6% solution; ip	....	15 min	......	17
11		Sheep	1/5 gr/lb; iv	....	30 min	Administer over 2 minutes	1
			Aves				
12	Avertin	Blackbird	0.15 g/lb; po (corn bait)	7	1.5 hr	Drug deteriorates rapidly (4 hr)	13
13		Starling	0.12 g/lb; po (corn bait)	1	3+ hr	Drug deteriorates rapidly (4 hr)	13
14		Wild turkey	0.06-0.09 g/lb; po (corn bait)	5-17	1-3 hr	Drug deteriorates rapidly (4 hr)	13
15		Pheasant	0.3 ml/kg in 3% solution; rec	....	......	......	3
16	Chloral hydrate	Domestic fowl	0.2-0.4 g/ml normal saline; iv	1-2	20-60 min	0.4-0.6 g is dangerous dose	10
17	Equithesin	Many species	2.0-2.5 ml/kg; im	1-2	1+ hr	2.5+ ml/kg is dangerous dose	7
18	Nembutal	Many species	60 mg/kg; im (pectoral)	....	......	......	6
19		Domestic fowl	1 ml/5 lb; iv	....	1-2 hr	......	15
20		Domestic pigeon	1.5 ml; im	....	......	Repeat injections: 1/2 of original	2
21		Robin	0.1 ml; im	....	......	......	2
22		Song sparrow	0.5 ml; im	....	......	......	2
			Reptilia and Amphibia[5]				
23	Avertin	Coachwhip snake	0.8 g/lb; po	3-5	6+ hr	Drug deteriorates quickly in solution	13
24		Copperhead	0.6 g/lb; po	3	6+ hr	Drug deteriorates quickly in solution	13
25		Snapping turtle	0.8 g/lb; po	5	48 hr	Prolonged drowsiness	13
26	Ether	Many species of snakes and lizards	On demand; inhalation	....	......	Artificial respiration often necessary	5
27	MS-222[6]	Axolotl, leopard frog	1:3,000 concentration; immersion	....	<30 min	No adverse effect	4
28		Common newt	1:3,000-1:1,000 concentration; immersion	....	30-60 min	No adverse effect	4, 11
29		Congo eel, mud puppy	1:250 concentration; immersion	....	30-60 min	No adverse effect	4
30		Frog, salamander (embryos & larvae)	1:10,000 concentration; immersion	....	Few min-2 da	No adverse effect	4
31		Leopard frog (larvae)	1:1,000 concentration; immersion	....	15-30 min	No adverse effect	4
32		Tiger salamander	1:2,000 concentration; immersion	....	15-30 min	No adverse effect	4
			Pisces and Chondrichthyes[5]				
33	MS-222[6]	Bluegill, bullhead, goldfish	1:3,500 concentration; immersion	....	4-10 min	No adverse effect; temperature, $20^{\circ}C \pm 1.5^{\circ}$	4
34		Brook trout, largemouth bass	1:31,000 concentration; immersion	....	20 min	Direct relation between amount of MS-222 and size of fish	4

/1/ For information on additional species, consult reference 12. /4/ One-quarter of dose in 30-40 seconds, remainder administered slowly. /5/ For information on additional species of Amphibia and Pisces, consult reference 4. /6/ Tricaine methanesulphonate.

continued

152. ANESTHETICS

	Drug	Animal	Dose and Route	Time to Act min	Duration	Remarks	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
			Pisces and Chondrichthyes[5]				
35	MS-222[6]	Brown trout	1:5,530 concentration; immersion	....	18-20 min	No adverse effect	4
36		Ray, shark	1 g/L of sea water (1:1,000 concentration); po and sprayed over gill exits of pharynx	<1	......	100-1,000 ml of solution, depending on size of animal; recovery within 5-30 minutes after return to water	9
			Turbellaria				
37	MS-222[6]	Planarian	1:1,500 concentration; immersion	15	......	Recovery approximately 30 minutes after return to well water	11

/5/ For information on additional species of Amphibia and Pisces, consult reference 4. /6/ Tricaine methanesulphonate.

Contributors: (a) Cowan, Ian McTaggart, (b) Achor, Leonard B.

References: [1] Awad, F. I. 1954. Vet. Record 66:226. [2] Bailey, R. E. 1953. Auk 70:497. [3] Balfour-Jones, S. E. 1936. Proc. Roy. Soc. Med. 29:709. [4] Bové, F. J. 1962. Sandoz News 3. [5] Brazenor, C. W., and K. Geoffrey. 1953. Copeia (3):165. [6] Durant, A. J. 1953. J. Am. Vet. Med. Assoc. 122:14. [7] Gandal, C. P. 1956. Ibid. 128:332. [8] Gates, W. H. 1932. Science 76:349. [9] Gilbert, P. W., and F. G. Wood. 1957. Science 126:212. [10] Hole, N. 1933. J. Comp. Pathol. Therap. 46:47. [11] Manner, H. W. 1957. Turtox News 35:134. [12] Mosby, H. S., ed. 1960. Manual of game investigational techniques. Edwards Brothers, Ann Arbor. [13] Mosby, H. S., and D. E. Cantner. 1956. Southwestern Vet. 9:132. [14] Rausch, R. 1947. J. Wildlife Management 11:189. [15] Warren, D. C., and H. M. Scott. 1953. Poultry Sci. 14:195. [16] Watson, D. F. 1953. North Am. Vet. 34:334. [17] Wright, J. G. 1952. Veterinary anesthesia. Ed. 3. Williams and Wilkins, Baltimore.

153. FIXATIVES AND CLEARING AGENTS

Part I. FIXATIVES

For additional information, consult references 4 and 6. Formol or formalin = 36-40% aqueous solution of formaldehyde, U.S.P. Alcohol may be ethanol, methanol, or isopropanol.

	Fixative	Recommended Uses	Ingredients	Duration of Application	Subsequent Treatment	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
1	Allen's B-15	Mammalian cytology	75 ml saturated aqueous solution of picric acid[1], 25 ml formol, 5 ml glacial acetic acid, 2 g urea. Just before use, add 1.5 g chromic acid.	12-24 hr	Brief tap-water rinse. Alcohol series to 70% overnight (small pieces of material).	5
2	Bouin's (picro-formol-acetic)	General fixative	75 ml saturated aqueous solution of picric acid[1], 25 ml formol, 5 ml glacial acetic acid.	24+ hr	Brief rinse in 30-50% alcohol. Store in 70% alcohol.	5
3	Carnoy's	Eggs of various invertebrates, glycogen, Nissl substance	10 ml glacial acetic acid, 30 ml chloroform, 60 ml 100% ethanol.	2-12 hr, according to size	Wash in 95% alcohol. Store in 70% alcohol.	5

/1/ Remove picric acid from spread sections with a few drops of saturated aqueous solution of lithium carbonate in any dilution of alcohol.

continued

153. FIXATIVES AND CLEARING AGENTS

Part I. FIXATIVES

	Fixative	Recommended Uses	Ingredients	Duration of Application	Subsequent Treatment	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
4	Champy's	Small animals; for good detail	0.4 g chromic anhydride CrO_3, 1.2 g potassium bichromate. Dissolve in 60 ml distilled water; add 40 ml 1% aqueous solution of osmic acid.	6-24 hr	Wash in tap water 12+ hr. Store in 70% alcohol.	1
5	Craf	Plants, general fixative	**Solution A**: 1 g chromic anhydride, 7 g glacial acetic acid, 92 ml distilled water. **Solution B**: 30 ml formalin, 70 ml distilled water. Just before use, mix equal parts of **A** and **B**.	12-24 hr	Wash in tap water 12-24 hr. Store in 70% alcohol.	1
6	Flemming's weak	Minute and delicate objects; for good cytoplasmic detail	0.25 g chromic acid, 0.10 g osmic acid, 0.10 ml glacial acetic acid, 100 ml water.	2-24 hr, according to size; best results at 0.5°C	Wash in tap water 2-24 hr. Store in 70% alcohol.	1
7	Formalin solution	Animals, general fixative	10 ml formalin, 90 ml distilled water.	24+ hr	Wash in tap water. Store in 10% formalin or 70% alcohol.	1
8	Formalin-acetic	Plant and animal tissues, general fixative	10 ml formalin, 5 ml glacial acetic acid, 85 ml 70% ethanol.	24+ hr	Wash in tap water. Store in 70% alcohol.	1
9	Gilson's	Small invertebrates, amphibian eggs, general purpose	15 ml 70-80% nitric acid, 4 ml glacial acetic acid, 100 ml 60% ethanol, 880 ml distilled water, 20 g mercuric chloride[2].	6+ hr	Wash in tap water. Store in 70% alcohol.	5
10	Helly's	Hematopoietic tissue	2.5 g potassium dichromate, 5 g mercuric chloride[2], 100 ml distilled water. Just before use, add 5 ml formalin.	6-24 hr	Wash 12+ hr in tap water, or in weak formol in dark.	1,3
11	Petrunkewitsch's	General purpose	**Solution A**: 100 ml distilled water, 1[illegible]c acid, 8 g cupric nitr[illegible]**ution B**: 100 ml 80% etha[illegible] g phenol, 6 ml ethyl ether. Just before use, mix 1 part **A** with 3 parts **B**.	24-72 hr	Wash in tap water. Store in 70% ethanol.	3
12	Susa-Heidenhain's	General purpose	4.5 g mercuric chloride[2], 80 ml distilled water. Mix, then add 0.5 g sodium chloride, 2 g trichloracetic acid, 4 ml glacial acetic acid, 20 ml formalin.	3-24 hr, according to size	Wash in tap water 12-24 hr, or in 70% alcohol.	1
13	Worcester's	Eggs of fish and amphibia; embryos; general fixative	90 ml 10% formalin saturated with mercuric chloride[2], 10 ml glacial acetic acid.	12-24 hr, according to size	Wash in tap water. Store in 70% alcohol.	5
14	Zenker's	Animal tissues, small pieces	25 g potassium dichromate, 5 g mercuric chloride[2], 5 ml glacial acetic acid, 100 ml water.	4-24 hr	Wash in tap water 12-24 hr. Store in 70% alcohol.	1

/2/ Remove mercuric chloride from spread sections with Gram's solution (formula: 5 ml water, 1 g iodine, 2 g potassium iodide; add water to make 300-ml solution). [2]

Contributor: Jones, Ruth McClung

References: [1] Davenport, H. A. 1960. Histological and histochemical technics. W. B. Saunders, Philadelphia. [2] Gray, P. 1954. The microtomist's formulary and guide. Blakiston, New York. [3] Gray, P. 1963. Handbook of basic microtechnique. Ed. 3. McGraw-Hill, New York. [4] Humason, G. L. 1962. Animal tissue techniques. W. H. Freeman, San Francisco. [5] Jones, R. M., ed. 1950. McClung's Handbook of microscopical technique. P. B. Hoeber, New York. [6] Lillie, R. D. 1954. Histopathologic technic and practical histochemistry. Blakiston, New York.

continued

153. FIXATIVES AND CLEARING AGENTS

Part II. CLEARING AGENTS

Recommended for use in cytology and histology, unless otherwise indicated. Alcohol may be ethanol, methanol, or isopropanol.

	Clearing Agent	Preceding Dehydrator	Method of Application	Duration of Application	No. of Changes	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
1	Anilin oil	30% alcohol	Immersion in mixtures 50:50 of anilin oil, and 30%, 50%, 70% alcohol; then pure anilin oil	1-2 hr each mixture; 2-4 hr pure anilin	1 for mixture; 2 for pure oil	1
2	Benzene	95 or 100% alcohol, or triethyl phosphate, or cellosolve	Immersion	Until translucent (1-3 hr)	3-5	1
3	Cedar wood oil[1]	80-100% alcohol	Layer alcohol over oil in vial; add specimen	Until specimen sinks to bottom	Fresh oil once after sinking	1
4	Petrolatum ether	95 or 100% alcohol, or triethyl phosphate, or cellosolve	Immersion	Until translucent (1-3 hr)	3-5	2
5	Toluene	95 or 100% alcohol, or triethyl phosphate, or cellosolve	Immersion	Until translucent (1-3 hr)	3-5	1
6	Xylene	95 or 100% alcohol, or triethyl phosphate, or cellosolve	Immersion	Until translucent (approximately 3 hr)	3-5	1

/1/ For use in cytology only.

Contributor: Jones, Ruth McClung

References: [1] Jones, R. M., ed. 1950. McClung's Handbook of microscopical technique. P. B. Hoeber, New York. [2] Lillie, R. D. 1954. Histopathologic technic and practical histochemistry. Blakiston, New York

154. STAINING METHODS

Part I. LIVING MATERIALS

	Material to be Stained	Animal	Stain	Application	Dose: Unit	Dose: No.	Subsequent Treatment	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
1	Bone matrix	Young mammals	1-2% aqueous solution of alizarin red; pH 8.0	Intraperitoneal	50-80 mg/kg	1 to several at desired intervals	Fix in 10% formalin (sections not decalcified).	2
2	Eggs	Amphibians, fishes	1% nile blue sulfate adsorbed on small, dry slips of agar	Apply agar slips to egg surface	15-30 min	1	At desired stage of development, fix in Zenker's fluid; wash briefly. Transfer to 1% aqueous solution of phosphomolybdic acid for 1 hr. Dehydrate in alcohol + 1% phosphomolybdic acid.	2
3		Amphibians, lamprey	1% bismarck brown, adsorbed on small, dry slips of agar	Apply agar slips to egg surface	15-30 min	1	Fix in 8.5 ml 100% alcohol, 15 ml glacial acetic acid. Transfer directly to cedar oil for storage.	2
4	Epithelial cells of convoluted tubules in kidney	Mouse	0.5% trypan blue in sterile water	Intraperitoneal	0.1-0.2 ml	4 at 48 hr intervals	Fix in 10% formalin; embed in paraffin.	2
5	Fats, fat cells	Cat	20% Sudan III, or Sudan IV, in olive oil	Pass by tube to stomach	5-10 ml	1	After 3-7 da, freeze sections of fat deposit areas.	1

continued

154. STAINING METHODS

Part I. LIVING MATERIALS

	Material to be Stained	Animal	Stain	Application	Dose: Unit	Dose: No.	Subsequent Treatment	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
6	Mitochondria	Mammals	Janus green-B, 1:10,000 in saline	Ventricle or aorta by gravity pressure, with temporary occlusion of inferior or superior vena cava	About 10 min, or until pancreas shows staining		Examine in saline.	2
7	Blood monocytes, tissue phagocytes	Rabbits	50% Higgins ink in sterile distilled water	Injection into marginal ear vein	5 ml	Daily for 3 da; twice thereafter at 3-da intervals	For blood smears, use Wright's stain. Fix tissues in 10% formalin; embed in paraffin.	2
8	Blood monocytes	Mouse	0.5% trypan blue in sterile water	Intraperitoneal	0.2-0.5 ml	4 at 48 hr intervals	Withdraw blood from tail vein and examine fresh or in dry smear.	1
9	Peripheral nerve endings	Mammals (usually cat)	0.2% aqueous methylene blue at 37°C	Intravenous injection after saline perfusion	Same amount as saline	1	After 30 min, immerse desired part in 0.1% methylene blue, at 37°C, until bluish, then in 8% ammonium molybdate for 30 min. Dehydrate in alcohol.	3
10	Phagocytes, loose connective tissue	Mouse	0.5% trypan blue in sterile water	Subcutaneous	0.2-0.5 ml	4 at 48 hr intervals	Fix in 10% formalin; embed in paraffin.	1
11		Common laboratory mammals	50% Higgins ink in sterile water	Subcutaneous	0.1-1.0 ml according to size		Fix in any good fixative; embed in paraffin.	2
12	Reticulo-endothelial phagocytes of spleen, liver, bone marrow, adrenals, lymph nodes	Mouse	0.5% trypan blue in sterile water	Intraperitoneal	0.2-0.5 ml	4 at 48 hr intervals	Fix in 10% formalin; embed in paraffin.	1
13	Teeth (dentin and enamel)	Young dog, before formation of permanent teeth	1% solution trypan blue in sterile water	Intraperitoneal	2-5 ml	5 at 1, 2, 3, 4, and 5 da intervals	Place head in 10% formalin at 35°C. Dehydrate jaws in alcohol, benzene; impregnate with benzol-damar for grinding.	2
14	Teeth	Young dog	1% aqueous solution of alizarin red	Intravenous and/or intraperitoneal	50-80 mg/kg	Several	Fix in formalin; grind.	2

Contributor: Jones, Ruth McClung

References: [1] Cowdry, E. V. 1952. Laboratory technique. Ed. 3. Williams and Wilkins, Baltimore. [2] Jones, R. M., ed. 1950. McClung's Handbook of microscopical technique. P. B. Hoeber, New York. [3] Lillie, R. D. 1954. Histopathologic technic and practical histochemistry. Blakiston, New York.

continued

154. STAINING METHODS

Part II. FIXED MATERIALS

Procedure (columns C-G): all solutions are aqueous, unless otherwise stated; H_2O refers to distilled water; ethanol, without qualification, refers to commercial "190 proof neutral grain spirits," and absolute (abs.) ethanol refers to "pure ethyl alcohol, U.S.P., 200 proof." ***Abbreviations:*** sat. = saturated; sol. = solution(s).

	Dye or Technique	Recommended Material	Procedure					Reference
			1st step	2nd step	3rd step	4th step	5th step	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
1	Heidenhain's iron hematoxylin	Nuclei, particularly mitotic figures, in sections	Mordant in 2.5% ferric alum overnight.	Rinse in H_2O. Stain 12-24 hr in 0.5% hematoxylin at least 1 mo old.	Rinse in H_2O. Differentiate in 2.5% ferric alum.	Place in alkaline tap water until blue. Steps 3 and 4 may be repeated.	Wash, dehydrate, clear, and mount in neutral balsam or synthetic substitute.	23
2	Ehrlich's hematoxylin	Nuclei in sections subsequently to be counterstained	Dissolve 0.7 g hematoxylin in 30 ml ethanol and 3 ml acetic acid. Mix 30 ml sat. sol. ammonia alum with 30 ml glycerol and add to dye sol. Ripen 3 mo.	Take sections to ethanol, then stain 0.5-2 min.	Apply ethanol from drop bottle until nuclei are differentiated.	Place in alkaline tap water until blue.	Wash, dehydrate, clear, and mount in neutral balsam or synthetic substitute.	6
3	Delafield's hematoxylin	Whole mounts of plants or animals	Dissolve 0.6 g hematoxylin in 70 ml sat. sol. ammonia alum; add 15 ml glycerol, 15 ml methanol, and 5 ml ethanol. Ripen 3 mo.	Take object to H_2O. Stain from 2 min (in full-strength stain for minute objects) to 2 da (in 1:10 dilution for a liver fluke).	Wash in H_2O until no color comes away.	Differentiate, if necessary, in 0.1% HCl in 70% ethanol. Place in alkaline tap water until blue throughout.	Wash, dehydrate, clear, and mount in neutral balsam or synthetic substitute.	1
4	Gray's celestin blue-B	Nuclei and mitotic figures in sections	Mix 1 g celestin blue-B with 0.5 ml H_2SO_4. Break up mass and add slowly, with constant stirring, 100 g 2.5% ferric alum with 14 ml glycerol heated to 50°C. Cool and adjust to pH 0.8 with H_2SO_4.	Take sections to H_2O. Stain 1 min or more (overstaining is impossible).	Rinse in tap water until no color comes away.	Dehydrate, clear, and mount in balsam.		2
5	Johansen's safranin	Nuclei in sections of animal tissue; nuclei and xylem in sections of plant tissues	Dissolve 0.1 g safranin-O in 50 ml methyl cellosolve; add 25 ml ethanol. Dissolve 1 g sodium acetate in 25 ml H_2O with 2 ml 40% formaldehyde; add to dye sol.	Take sections to H_2O. Stain 1-3 da.	Differentiate in 0.5% picric acid in 65% ethanol.	Wash in running tap water until yellow color is removed.	Dehydrate, clear, and mount in balsam.	11
6	Bismarck brown	Whole mounts of small plants or animals	Take objects to H_2O. Stain 1-5 min in 1% bismarck brown.	Wash until no color comes away.	Dehydrate, clear, and mount in balsam.			11
7	Grenacher's alcoholic borax carmine	Whole mounts of plants or animals; nuclei in sections of plant or animal tissues	Boil 1.5 g carmine with 2 g borax in 50 ml H_2O for 30 min. Cool; add 50 ml 70% ethanol. Leave 2 da and filter.	Take objects to H_2O. Stain overnight.	Differentiate objects in 0.1% HCl in 70% ethanol until clear pink (sections rarely require differentiation).	Dehydrate, clear, and mount in balsam.		9

continued

154. STAINING METHODS

Part II. FIXED MATERIALS

	Dye or Technique	Recommended Material	Procedure: 1st step	2nd step	3rd step	4th step	5th step	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
8	Mayer's paracarmine	Whole mounts of small invertebrates, particularly marine forms and their larvae	Dissolve 1 g carmine acid in 70% ethanol; add 4 g strontium chloride and 0.5 g aluminum chloride.	Take objects to 50% ethanol. Stain overnight.	Differentiate in 0.1% strontium chloride in 70% ethanol.	Dehydrate, clear, and mount in balsam.		18
9	La Cour's aceto-orcein	Chromosomes in squashes	Dissolve 1 g orcein in equal parts acetic acid and water.	Squash material in stain under cover. Examine at intervals until maximum intensity of stain is reached.	Place slide on "dry ice" until cover slip is well frosted.	Pry off cover slip with safety razor blade. Place slide in 70% ethanol.	Dehydrate, clear, and mount in balsam.	13
10	Eosin-Y; ethyl eosin	Contrast stain for black or blue nuclei, particularly in sections of animal material	Dissolve 0.5 g eosin-Y in H_2O, or 0.5 g ethyl eosin in ethanol.	Take sections with prestained nuclei to H_2O for eosin-Y, or to ethanol for ethyl eosin.	Place sections in stain until preferred intensity is reached.	Dehydrate, clear, and mount in balsam.		13
11	Light green; fast green FCF	Contrast stain for red nuclei, particularly in sections of plant tissues	Dissolve 0.5 g of either dye in ethanol.	Take sections with prestained nuclei to ethanol.	Place sections in stain until preferred intensity is reached.	Dehydrate, clear, and mount in balsam.		13
12	Smith's picro-spirit blue	Double contrast stain for red nuclei, particularly in sections of embryos with heavy yolk	Dissolve 1 g picric acid in 100 ml abs. ethanol. Saturate with spirit blue (about 1.2 g).	Bulk stain amphibian embryos with Grenacher's alcoholic borax carmine. Cut 10-μ sections. Take to abs. ethanol.	Place in stain 2 min.	Differentiate in abs. ethanol.	Clear in xylene. Steps 3, 4, and 5 may be repeated. Mount in balsam.	21
13	Shumway's picro-indigo carmine	Double contrast stain for red nuclei, particularly in sections of amniote embryos	Mix equal parts of sat. sol. of picric acid and indigo carmine.	Take sections with prestained nuclei to water. Stain 5 min.	Differentiate in 70% ethanol.	Transfer to abs. ethanol for not more than 15 sec.	Clear in xylene, mount in balsam.	20
14	Patay's ponceau 2R-light green	Double contrast stain for blue or black nuclei in sections	Take sections with prestained nuclei to H_2O.	Stain 2 min in 1% ponceau 2R.	Rinse briefly in H_2O. Differentiate 2 min in 1% phosphomolybdic acid.	Rinse briefly in H_2O. Stain 30 sec in 0.5% light green in 90% ethanol.	Dehydrate, clear, and mount in balsam.	19
15	Gray's ponceau 2R-orange 2	Double contrast stain for blue or black nuclei in sections	Take sections with prestained nuclei to H_2O.	Stain 2 min in 100 ml H_2O, 0.4 g ponceau 2R, 0.6 g orange 2.	Blot slides, then dip up and down in abs. ethanol until differentiated.	Clear in xylene, mount in balsam.		8
16	Masson's triple contrast	Triple contrast stain for blue or black nuclei in sections	Take sections with nuclei, prestained preferably with Gray's celestin blue-B, to H_2O.	Stain 5 min in 100 ml H_2O, 1 ml acetic acid, 0.35 g acid fuchsin, 0.65 g ponceau 2R.	Rinse briefly in H_2O. Differentiate 5 min in 1% phosphomolybdic acid.	Rinse briefly in H_2O; drain. Flood slide with sat. sol. anilin blue in 2.5% acetic acid; leave 2-5 min. Differentiate in 1% acetic acid.	Pass directly to 0.1% acetic acid in abs. ethanol. Dehydrate, clear in xylene containing 1% salicylic acid; mount in balsam similarly acidified.	17

continued

154. STAINING METHODS

Part II. FIXED MATERIALS

	Dye or Technique	Recommended Material	Procedure					Reference
			1st step	2nd step	3rd step	4th step	5th step	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
17	Mallory's triple stain	General stain for sections of animal tissues	Stain 2 min in 1% acid fuchsin.	Rinse in H_2O. Differentiate 2 min in 1% phosphotungstic acid.	Rinse in H_2O. Stain 10 min in 100 ml H_2O, 0.5 g methyl blue, 1 g orange G2, 1 g oxalic acid.	Wash in H_2O until no color comes away. Dip up and down in abs. ethanol until differentiated.	Clear in xylene and mount in balsam preferably containing 1% salicylic acid.	15
18	Johansen's quadruple stain	General stain for sections of plant tissues	Stain 24 hr in Johansen's safranin, but do not differentiate. Rinse in H_2O. Stain 10-15 min in 1% methyl violet.	Differentiate 15 sec in mixture of equal parts ethanol, methyl cellosolve, tertiary butanol.	Stain 10-15 min in sat. sol. of fast green FCF in 13 ml equal parts ethanol and methyl cellosolve, 36 ml ethanol, 36 ml tertiary butanol, 12 ml acetic acid.	Rinse in 0.5% acetic acid in equal parts ethanol and tertiary butanol. Stain 3 min in sat. sol. of orange G in equal parts ethanol, tertiary butanol, and methyl cellosolve.	Rinse in equal parts ethanol, methyl cellosolve, and clove oil. Rinse in equal parts ethanol, clove oil, and xylene. Clear in xylene and mount in balsam.	10
19	Wright's methylene blue-eosin	Blood smears	Prepare blood smear; allow to dry.	Place 3 drops of Wright's stain on smear.	Exactly 1 min later, add 6 drops of phosphate pH 6.4 buffer.	2 min later, wash thoroughly with H_2O.	Allow slide to dry.	24
20	Anderson's "Weigert-Pal" stain	Demonstration of nerve tracts by staining myelin sheaths in 30-μ frozen sections	Boil together 100 ml H_2O, 5 g potassium dichromate, 2.5 g chromic fluoride; cool, filter. To this stock sol., add immediately before use, 10% of 2% calcium hypochlorite. Stain sections 2-3 da.	Transfer sections to stock mordant sol. without hypochlorite for 15-60 min.	Dissolve 0.5 g hematoxylin in 10 ml abs. ethanol; add 3 ml 2% calcium hypochlorite. Shake well; dilute with H_2O to 100 ml; add 3 ml acetic acid. Transfer sections from mordant, without rinsing, and heat to 50°C for 1 hr.	Transfer sections, without washing, to 100 ml H_2O, 2.5 g boron dichromate, 1 g sodium sulfate. Wash thoroughly. Transfer to fresh 0.25% potassium permanganate until brown.	Transfer, without washing, to 100 ml H_2O, 0.5 g potassium sulfite, 0.5 g oxalic acid until bleached. Repeat until differentiation is complete. Wash thoroughly, dehydrate, clear, and mount in balsam.	3
21	Davenport-Windle-Rhine protein silver stain	Demonstration of nerve tracts by staining axis cylinders in paraffin sections	Cut 10-μ paraffin sections of material fixed in 50 ml H_2O, 50 ml ethanol, 5 ml *p*-nitrophenol, 10 ml formamide.	Deparaffinize mounted sections and bring to H_2O. Place in 5% silver nitrate at 60°C for 1 hr.	Wash in 3 successive, 30-sec changes of H_2O. Transfer to 0.2% protargol for 1 hr.	Rinse quickly in H_2O. Transfer to 100 ml H_2O, 5 g sodium sulfite (desiccated), 1 g hydroquinone, 0.5 g potassium metaborate for 1 min. Wash thoroughly in running water.	Transfer to 0.2% gold chloride until gray. Rinse quickly and place in 0.4% oxalic acid until section just starts to darken. Rinse. Fix in 5% sodium thiosulfate. Wash thoroughly, dehydrate, clear, and mount in balsam.	4

continued

Part II. FIXED MATERIALS

	Dye or Technique	Recommended Material	Procedure 1st step	2nd step	3rd step	4th step	5th step	Reference
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
22	Kull's method for mitochondria	Mitochondria in 5-μ paraffin sections	Fix small pieces for 25 hr in 100 ml H_2O, 0.5 g osmic acid, 0.5 g chromic acid, 1.25 g potassium dichromate.	Wash 30 min in H_2O. Transfer to 85 ml H_2O, 15 ml pyroligneous acid, 1 g chromic acid for 24 hr.	Wash 30 min in H_2O. Transfer to 3% potassium dichromate for 24 hr. Wash 24 hr in running water. Cut 5-μ paraffin sections; take sections to H_2O.	Saturate hot anilin with acid fuchsin. Shake thoroughly with equal quantity of H_2O. Separate and retain aqueous fraction. Flood sol. on slide and heat to steaming for 1 min.	Rinse quickly in H_2O. Place in 0.5% toluidine blue for 1-2 min. Rinse quickly in H_2O. Differentiate 0.5% aurantia in 70% ethanol. Dehydrate in acetone, clear in xylene, and mount in balsam.	12
23	Ludford's method for Golgi apparatus	Golgi in 5-μ paraffin sections	Fix small pieces (earthworm ovary is excellent) for 1 hr in 100 ml H_2O, 0.5 g osmic acid, 4 g mercuric chloride, 1 g sodium chloride.	Place specimen on bottom of 30-ml stoppered bottle; add just enough 2% osmic acid to cover specimen. Keep 2 wk at room temperature.	Fill bottle with H_2O and keep 2 da at 38°C. Wash in running water.	Cut 5-μ paraffin sections. Mount and deparaffinize with xylene.	Examine sections of Golgi apparatus; if not clear, place in turpentine until differentiated. Wash in xylene, and mount in balsam.	14
24	Hucker's crystal violet	Bacterial smears	Dissolve 2 g crystal violet in 20 ml ethanol. Dissolve 0.8 g ammonium oxalate in 80 ml H_2O; add to dye sol.	Spread thin film of bacteria and allow to dry. Pass through flame.	Flood dye sol. on smear. Leave 30 sec.	Wash off dye sol. with jet H_2O from wash bottle.	Allow film to dry.	5
25	Gram's stain	Demonstration of gram-positive bacteria	Follow steps 1, 2, and 3 for Hucker's crystal violet.	Rinse quickly in beaker of H_2O; add few drops of 0.5% iodine in 1% potassium iodide. Leave 1 min.	Rinse quickly in H_2O. Place in abs. ethanol until no color comes away.	Stain 5-10 sec in 1% safranin-O. Wash and dry.		5
26	Margolena's stain	Demonstration of parasitic fungi in sections of plant tissues	Dissolve 0.1 g thionine and 5 g phenol in 95 ml H_2O. Stain sections 1 hr.	Rinse in H_2O. Place in 0.5% light green in ethanol for 1 min.	Wash in H_2O until no color comes away. Dehydrate in abs. ethanol.	Mix 30 ml sat. sol. orange G in ethanol with 60 ml sat. sol. erythrosin in clove oil. Stain 1-2 min.	Rinse in clove oil, clear in xylene, and mount in balsam.	16
27	Alizarin red	Demonstration of bone, or calcified areas, in whole mounts of small animals	Fix or preserve specimens in ethanol, or formaldehyde made alkaline with borax.	Bring specimens to 70% ethanol. Stain 1-12 hr in mixture of 1 ml sat. ethanol sol. alizarin red S with 100 ml sat. sol. borax in 70% ethanol.	Transfer to sat. sol. borax in 90% ethanol until no color comes away.	Dehydrate, clear, and mount in balsam.		7

continued

154. STAINING METHODS

Part II. FIXED MATERIALS

	Dye or Technique	Recommended Material	Procedure					Reference
			1st step	2nd step	3rd step	4th step	5th step	
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
28	Van Wijhe's stain	Demonstration of cartilage in whole mounts of embryos	Preserve specimens in any preservative not containing picric acid.	Wash in running water overnight. Take to 70% ethanol.	Stain 24 hr in 70% ethanol containing 0.1% each of HCl and toluidine blue.	Wash in 70% ethanol containing 0.1% HCl until no color comes away.	Dehydrate, clear, and mount in balsam.	22

Contributor: Gray, Peter

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155. HISTOCHEMICAL TESTS

Abbreviations: conc. = concentrated; sat. = saturated; sol. = solution.

	Substance	Preparation of Tissue	Preparation of Reagents	Test Method	Result	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
1	Lipids	Fix in 4% formaldehyde containing 1% calcium chloride. Cut frozen sections, if necessary, after embedding in gelatin.	Digest 1 g Sudan black B in 100 ml 60% triethyl phosphate at 100°C for 5 min with constant agitation. Cool, then filter.	Stain section 2-5 min. Wash in 60% triethyl phosphate. Wash in H_2O and stain carmine-light green. Mount in aqueous medium.	Lipid granules, black; nuclei, red; cytoplasm, green.	4
2	Cholesterol	Cut frozen sections of fresh or formaldehyde-fixed material.		Strand section on slide. Drain well. Cover with 2 drops conc. H_2SO_4 for 10 sec. Add 2 drops acetic anhydride, wait 10 sec, then wash thoroughly with acetic anhydride. Place cover slip on section.	Cholesterol shows green, or blue-green. Preparation cannot be preserved.	10

continued

155. HISTOCHEMICAL TESTS

	Substance	Preparation of Tissue	Preparation of Reagents	Test Method	Result	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
3	Glycogen	Fix in ethanol at 0°C. Cut 10-μ paraffin sections and mount on slide; deparaffinize in xylene. Rinse in equal parts ethanol and ether. Dip in collodion U.S.P.	Boil 2 g carmine, 1 g potassium carbonate, and 5 g potassium chloride in 60 ml H_2O for 5 min. Cool, then add 20 ml ammonium hydroxide. For use, dilute 10 ml of this stock sol. with 15 ml ammonium hydroxide and 15 ml ethanol.	Stain collodionized sections in celestin blue B. Wash thoroughly in water. Stain in carmine 15 min. Rinse thoroughly in methanol, dehydrate in acetone, clear in xylene, and mount in balsam.	Nuclei, black; glycogen granules, scarlet.	1
4	Starch	Fix in any dichromate--chromic acid--formaldehyde fixative. Cut paraffin sections.	Saturate hot anilin with acid fuchsin. Shake well, separate, and retain water fraction.	Pour acid fuchsin stain on sections; heat to steaming for 1 min. Rinse in H_2O and place in 5% aurantia in ethanol until no color comes away. Rinse in 70% ethanol and transfer to 2% tannic acid for 15 min. Transfer directly to 1% methyl green for 10 min. Differentiate in ethanol until starch grains are sharply distinct.	Plastids, proplastids, and mitochondria, red; starch, green. The standard iodine test for starch does not yield permanent preparations.	6
5	Mucin	Cut paraffin sections of material fixed in any mercuric chloride or dichromate fixative.		Stain 10-40 sec in 1% Alcian Blue. Rinse quickly in H_2O and transfer for 2 hr to 0.5% borax in 80% ethanol. Dehydrate and mount in balsam.	Mucin, bright blue. Stained sections may be counterstained in hematoxylin-eosin if further histological detail is desired.	12
6	Celluloses	Sections of plant tissues, or teased fibers.	Dissolve 2 g iodine and 5 g potassium iodide in a small amount of H_2O. Dilute to 100 ml. Add 10 ml iodine sol. and 0.25 ml glycerol to 90 ml H_2O.	Cover specimen with iodine sol. for 15 sec. Blot dry. Add 1 drop of sat. aqueous sol. lithium carbonate. Apply cover slip.	Pure cellulose, blue; impure celluloses, various shades of green, yellow, and brown.	9
7	Lignin	Sections of plant tissues, or teased fibers.		Place in 1% phloroglucinol for 2 min. Blot and add 1 drop of HCl.	Lignin, red.	9
8	Chitin	Sections of tissues.	Dissolve 10 g anilin hydrochloride in 100 ml 1% HCl. Stain sections 5 min.	Transfer to 7.5% potassium dichromate for 1 min. Rinse in H_2O and place in alkaline tap water until color changes from green to blue.	Chitin, blue.	2
9	DNA	Sections or smears of either animal or plant material.	Boil 1 g magenta ("basic" fuchsin) in 100 ml H_2O. Add 20 ml *N* HCl. Cool, filter, and add 5 ml 10% sodium bisulfite. Leave in dark 24 hr.	Hydrolyze material 20 min in *N* HCl. Stain 2 hr in dark. Bleach cytoplasm 1-2 min in freshly made 100 ml H_2O, 5 ml 10% sodium bisulfite, 5 ml *N* HCl. Counterstain in light green if desired. Dehydrate, clear, and mount in balsam.		3
10	RNA	10-μ paraffin sections of tissues.	Shake 0.5 g methyl green with successive batches of chloroform until all chloroform-soluble color is removed. Add 13 ml of purified dye sol. to 50 ml pH 4.8 acetate buffer and 37 ml 0.5% pyroam G.	Take sections to H_2O. Blot. Stain 30 min. Blot. Pass to acetone 1 min, and 50:50 acetone-xylene 1 min. Clear in xylene and mount in balsam.	RNA, blue to blue-green; DNA, red.	5

continued

155. HISTOCHEMICAL TESTS

	Substance	Preparation of Tissue	Preparation of Reagents	Test Method	Result	Reference
	(A)	(B)	(C)	(D)	(E)	(F)
11	Proteins	10-μ sections of neutral formaldehyde-fixed material.	Mix 95 ml ethanol with 0.5 ml 0.2 *N* sodium hydroxide. Add 0.5 g 2, 4-dinitro-fluorobenzene.	Take sections to H_2O. Stain 24 hr. Rinse thoroughly in ethanol, then H_2O. Bleach in 5% sodium thiosulfate 40 min at 37°C. Rinse in H_2O. Add 5 ml ice-cold 4*N* H_2SO_4 to 100 ml ice-cold 5% sodium nitrate. Soak bleached sections 4-5 min. Rinse in H_2O. Transfer to 2% H-acid in barbitone-acetate pH 9.2 buffer for 15 min. Rinse in H_2O, dehydrate, clear, and mount in balsam.	Protein, purple-red.	11
12	Iron	10-μ, or thicker, sections of tissues fixed in iron-free, neutral formaldehyde.		Take sections to H_2O. Place in 2% potassium ferrocyanide with equal volume of 0.2 *N* HCl and stain 20 min. Dehydrate, clear, mount in balsam.	Reactive iron, blue. Non-reactive iron (e.g., in hemoglobin) may be rendered reactive by treating sections for 30 min, before staining, in alkaline H_2O_2.	7
13	Hemoglobin	10-μ, or thicker, sections of tissues fixed in neutral formaldehyde.	Dissolve 1-2 g benzidine in 100 ml methanol with 1.2 ml acetic acid. Add 0.12 g sodium nitroprusside.	Deparaffinize sections in xylene. Remove xylene completely in several changes of methanol. Stain 10 min. Wash in 50 ml methanol, 25 ml ether, 25 ml 3% H_2O_2. Dehydrate, clear, and mount in balsam.	Hemoglobin, bright blue.	8
14	Carotene	Immerse plant tissues in 20 ml sat. aqueous sol. potassium hydroxide, 15 ml ethanol, 85 ml H_2O in dark until all green removed.		Wash pieces thoroughly in H_2O. Place fragment on slide, blot, and cover with H_2SO_4.	Areas of dark blue crystals indicate carotene locations.	13

Contributor: Gray, Peter

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APPENDIXES

Appendix I. ESTIMATED NUMBER OF SPECIES: ANIMAL AND PLANT KINGDOMS

	Phylum and Class	No. of Species
	(A)	(B)
	Animal Kingdom[1] [3]	
1	Chordata	44,794
2	Mammalia	4,500
3	Aves	8,590
4	Reptilia	5,000
5	Amphibia	2,000
6	Pisces, Chondrichthyes, Agnatha	23,000
7	Cephalochordata[2]	13
8	Urochordata[2]	1,600
9	Hemichordata[2]	91
10	Echinodermata	5,700
11	Pogonophora	43
12	Chaetognatha	50
13	Arthropoda	765,257
14	Tardigrada	280
15	Pentastomida	60
16	Pycnogonida	440
17	Arachnida	30,000
18	Merostomata	4
19	Crustacea	25,000
20	Insecta	700,000
21	Symphyla, Chilopoda, Diplopoda, Pauropoda	9,400
22	Onychophora	73
23	Annelida	7,000
24	Echiuroidea	80
25	Sipunculoidea	275
26	Mollusca	100,000
27	Brachiopoda	260
28	Phoronida	15
29	Polyzoa	4,000
30	Entoprocta	60
31	Acanthocephala	300
32	Aschelminthes	11,995
33	Nematoda	10,000
34	Nematomorpha	250
35	Priapulida	5
36	Echinoderida	100
37	Gastrotricha	140
38	Rotifera	1,500
39	Nemertina	550
40	Platyhelminthes	15,000
41	Ctenophora	80
42	Cnidaria	9,600
43	Porifera	4,200
44	Mesozoa	50
45	Protozoa	30,000
	TOTAL	999,309
	Plant Kingdom[3] [1]	
46	Vira	65
47	Bacteriophyta	1,478
48	Myxophyta	465
49	Myxomyceteae	421
50	Acrasieae	21
51	Plasmodiophoreae	23
52	Fungi	30,021
53	Phycomycetes	1,060
54	Ascomycetes	7,297
55	Basidiomycetes	15,950
56	Fungi Imperfecti	5,714
57	Lichenes	16,128
58	Phycolichenes	1
59	Ascolichenes	16,119
60	Basidiolichenes	8
61	Algae	16,951
62	Cyanophyta[4]	1,227
63	Euglenophyta[4]	481
64	Pyrrophyta[4]	1,155
65	Chrysophyta[4]	5,453
66	Chlorophyta[4]	4,913
67	Charophyta[4]	207
68	Phaeophyta[4]	963
69	Rhodophyta[4]	2,552
70	Bryophyta	22,789
71	Musci	14,252
72	Hepaticae	8,241
73	Anthocerotae	296
74	Pteridophyta	9,640
75	Spermatophyta	188,991
76	Gymnospermae	696
77	Angiospermae	188,295
78	Monocotyledoneae[5]	41,714
79	Dicotyledoneae[5]	146,581
	TOTAL	286,528

/1/ Number of hybrids reported: Mammalia, 300; Aves, 1,599; Reptilia, 40; Amphibia, 271; Pisces, 212; Protochordata, 1; Echinodermata, 36; Arthropoda, 289; Mollusca, 12. [2] /2/ Subphylum. /3/ Number of hybrids reported: Schizomycophyta, 2; Eumycophyta, 67; Chlorophyta, 19; Bryophyta, 43; Pteridophyta, 158; Spermatophyta, 15,000 (exclusive of orchids). [2] /4/ Division. /5/ Subclass.

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Appendix II. TAXONOMIC CLASSIFICATION: LIVING ANIMALS

Phylum: **CHORDATA**

Subphylum: VERTEBRATA
Class: **Mammalia** [6]
Subclass: Theria
Infraclaas: Eutheria
Order: Artiodactyla
Suborder: Ruminantia
Suborder: Tylopoda
Suborder: Suiformes
Order: Perissodactyla
Suborder: Ceratomorpha
Suborder: Hippomorpha
Order: Sirenia
Order: Hyracoidea
Order: Proboscidea
Order: Tubulidentata
Order: Carnivora
Suborder: Pinnipedia
Suborder: Fissipeda
Order: Cetacea
Suborder: Mysticeti
Suborder: Odontoceti
Order: Rodentia
Suborder: Hystricomorpha
Suborder: Myomorpha
Suborder: Sciuromorpha
Order: Lagomorpha
Order: Pholidota
Order: Edentata
Order: Primates
Suborder: Anthropoidea
Suborder: Prosimii
Order: Chiroptera
Suborder: Microchiroptera
Suborder: Megachiroptera
Order: Dermoptera
Order: Insectivora
Infraclass: Metatheria
Order: Marsupialia
Subclass: Prototheria
Order: Monotremata
Class: **Aves** [7]
Order: Passeriformes
Suborder: Passeres
Suborder: Menurae
Suborder: Tyranni
Suborder: Eurylaimi
Order: Piciformes
Suborder: Pici
Suborder: Galbulae
Order: Coraciiformes
Suborder: Bucerotidae
Suborder: Coracii
Suborder: Meropes
Suborder: Alcedines
Order: Trogoniformes
Order: Coliiformes
Order: Apodiformes
Suborder: Trochili
Suborder: Apodi
Order: Caprimulgiformes
Suborder: Caprimulgi
Suborder: Steatornithes
Order: Strigiformes
Order: Cuculiformes
Suborder: Cuculi
Suborder: Musophagi
Order: Psittaciformes
Order: Columbiformes
Suborder: Columbae
Suborder: Pterocletes
Order: Charadriiformes
Suborder: Alcae
Suborder: Lari
Suborder: Charadrii
Order: Gruiformes
Suborder: Otides
Suborder: Cariamae
Suborder: Eurypygae
Suborder: Rhynocheti
Suborder: Heliornithes
Suborder: Grues
Suborder: Turnices
Suborder: Mesitornithides
Order: Galliformes
Suborder: Opisthocomi
Suborder: Galli
Order: Falconiformes
Suborder: Falcones
Suborder: Cathartae
Order: Anseriformes
Suborder: Anseres
Suborder: Anhimae
Order: Ciconiiformes
Suborder: Phoenicopteri
Suborder: Ciconiae
Suborder: Balaenicipites
Suborder: Ardeae
Order: Pelecaniformes
Suborder: Fregatae
Suborder: Pelecani
Suborder: Phaëthontes
Order: Procellariiformes
Order: Podicipediformes
Order: Gaviiformes
Order: Tinamiformes
Order: Apterygiformes
Order: Casuariiformes
Order: Rheiformes
Order: Struthioniformes
Order: Sphenisciformes
Class: **Reptilia** [4,5]
Order: Serpentes
Order: Sauria
Order: Crocodylia
Order: Chelonia
Suborder: Pleurodira
Suborder: Cryptodira
Order: Rhynchocephalia
Class: **Amphibia** [2,4]
Order: Gymnophiona
Order: Salientia
Suborder: Diplasiocoela
Suborder: Procoela
Suborder: Anomocoela
Suborder: Opisthocoela
Suborder: Amphicoela
Order: Caudata
Suborder: Meantes
Suborder: Proteida
Suborder: Salamandroidea
Suborder: Ambystomoidea
Suborder: Cryptobranchoidea
Class: **Pisces** [3,4]
Subclasa: Crossopterygii
Order: Dipnoi
Order: Actinistia
Subclass: Neopterygii
Order: Synbranchii
Suborder: Synbranchoidea
Suborder: Alabetoidea
Order: Opisthomi
Order: Pediculati
Suborder: Ceratioidea
Suborder: Antennarioidea
Suborder: Lophioidea
Order: Haplodoci
Order: Xenopterygii
Order: Malacicthyes
Order: Plectognathi
Suborder: Tetraodontoidea
Suborder: Balistoidea
Order: Discocephali
Order: Heterosomata
Order: Hypostomides
Order: Thoracostei
Order: Scleroparei
Suborder: Cephalacanthoidea
Suborder: Scorpaenoidea
Order: Percomorphi
Suborder: Polynemoidea
Suborder: Mugiloidea
Suborder: Channoidea
Suborder: Anabantoidea
Suborder: Stromateoidea
Suborder: Ophidioidea
Suborder: Blennioidea
Suborder: Callionymoidea
Suborder: Gobioidea
Suborder: Scombroidea
Suborder: Trichiuroidea
Suborder: Siganoidea
Suborder: Acanthuroidea
Suborder: Percoidea
Order: Zeomorphi
Order: Berycomorphi
Suborder: Xenoberyces
Suborder: Berycoidea
Order: Allotriognathi
Order: Anacanthini
Order: Solenichthyes
Suborder: Aulostomi
Suborder: Lophobranchi
Order: Salmopercae
Order: Microcyprini
Order: Synentognathi
Suborder: Exocoetoidea
Suborder: Scombresocoidea
Order: Heteromi
Order: Apodes
Order: Ostariophysi
Suborder: Siluroidea
Suborder: Cyprinoidea
Order: Lyomeri
Order: Giganturoidea
Order: Iniomi
Suborder: Alepisauroidea
Suborder: Myctophoidea
Order: Haplomi

continued

Appendix II. TAXONOMIC CLASSIFICATION: LIVING ANIMALS

Order: Isospondyli
Suborder: Gonorhynchoidea
Suborder: Mormyroidea
Suborder: Notopteroidea
Suborder: Osteoglossoidea
Suborder: Salmonoidea
Suborder: Stomiatoidea
Suborder: Clupeoidea
Order: Ginglymodi
Order: Protospondyli
Subclass: Palaeopterygii
Order: Chondrostei
Order: Cladistia
Class: **Chondrichthyes** [3,4]
Subclass: Holocephali
Subclass: Elasmobrancnii
Order: Batoidei
Order: Selachii
Suborder: Squaloidea
Suborder: Galeoidea
Suborder: Notidanoidea
Class: **Agnatha** [3,4]
Order: Petromyzones
Order: Myxini
Subphylum: CEPHALOCHORDATA [4]
Subphylum: UROCHORDATA [4]
Class: **Larvacea**
Order: Copelata
Class: **Thaliacea**
Order: Salpida
Order: Doliolida
Order: Pyrosomida
Class: **Ascidiacea**
Order: Pleurogona
Suborder: Aspiriculata
Suborder: Stolidobranchiata
Order: Enterogona
Suborder: Phlebobranchiata
Suborder: Aplousobra
Subphylum: HEMICHORDATA
Class: **Planctosphaeroidea**
Class: **Pterobranchia**
Order: Cephalodiscida
Order: Rhabdopleurida
Class: **Enteropneusta**

Phylum: **ECHINODERMATA** [4]

Subphylum: ELEUTHEROZOA
Class: **Ophiuroidea**
Order: Euryalae
Order: Ophiurae
Class: **Asteroidea**
Order: Forcipulata
Order: Spinulosa
Order: Phanerozona
Class: **Echinoidea**
Subclass: Euechinoidea
Superorder: Atelostomata
Order: Spatangoida
Order: Holasteroida
Order: Cassiduloida
Order: Nucleolitoida
Superorder: Gnathostomata
Order: Clypeasteroida
Suborder: Rotulina
Suborder: Scutellina
Suborder: Laganina
Suborder: Clypeasterina

Order: Holectypoida
Suborder: Echinoneina
Superorder: Echinacea
Order: Echinoida
Order: Temnopleuroida
Order: Arbacioida
Order: Phymosomatoida
Order: Hemicidaroida
Superorder: Diadematacea
Order: Echinothurioida
Order: Diadematoida
Subclass: Perischoechinoidea
Order: Cidaroida
Class: **Holothuroidea**
Order: Apoda
Order: Molpadonia
Order: Dendrochirota
Order: Elasipoda
Order: Aspidochirota
Subphylum: PELMATOZOA
Class: **Crinoidea**
Order: Articulata

Phylum: **POGONOPHORA** [4]

Order: Thecanephria
Order: Athecanephria

Phylum: **CHAETOGNATHA** [4]

Phylum: **ARTHROPODA**

Class: **Tardigrada** [4]
Order: Eutardigrada
Order: Heterotardigrada
Class: **Pentastomida** [4]
Order: Porocephalida
Order: Cephalobaenida
Class: **Pycnogonida** [4]
Order: Pycnogonomorpha
Order: Ascorhynchomorpha
Order: Nymphonomorpha
Order: Colossendeomorpha
Class: **Arachnida** [4]
Order: Acari
Order: Araneae
Order: Opiliones
Order: Solifugae
Order: Ricinulei
Order: Palpigradi
Order: Amblypygi
Order: Uropygi
Order: Pseudoscorpiones
Order: Scorpiones
Class: **Merostomata** [4]
Order: Xiphosura
Class: **Crustacea** [4]
Subclass: Malacostraca
Superorder: Eucarida
Order: Decapoda
Suborder: Reptantia
Suborder: Natantia
Order: Euphausiacea
Superorder: Pancarida
Order: Thermosbaenacea
Superorder: Hoplocarida
Order: Stomatopoda
Superorder: Peracarida
Order: Amphipoda
Order: Spelaeogriphacea

Order: Isopoda
Order: Gnathiidea
Order: Tanaidacea
Order: Cumacea
Order: Mysidacea
Superorder: Syncarida
Order: Bathynellacea
Order: Anaspidacea
Superorder: Leptostraca
Order: Nebaliacea
Subclass: Cirripedia
Order: Ascothoracica
Order: Rhizocephala
Order: Acrothoracica
Order: Thoracica
Subclass: Branchiura
Subclass: Mystacocarida
Order: Derocheilocarida
Subclass: Copepoda
Order: Lernaeopodoida
Order: Caligoida
Order: Notodelphyoida
Order: Harpacticoida
Order: Cyclopoida
Order: Monstrilloida
Order: Calanoida
Subclass: Ostracoda
Order: Platycopa
Order: Podocopa
Order: Cladocopa
Order: Myodocopa
Subclass: Branchiopoda
Order: Cephalocarida
Order: Cladocera
Order: Conchostraca
Order: Notostraca
Order: Anostraca
Class: **Insecta** [1]
Subclass: Pterygota
Order: Hymenoptera
Suborder: Apocrita
Suborder: Symphyta
Order: Siphonaptera
Order: Diptera
Suborder: Brachycera
Suborder: Nematocera
Order: Lepidoptera
Suborder: Jugatae
Suborder: Frenatae
Order: Trichoptera
Order: Mecoptera
Order: Strepsiptera
Order: Coleoptera
Suborder: Polyphaga
Suborder: Adephaga
Suborder: Archostemata
Order: Neuroptera
Order: Homoptera
Suborder: Sternorrhyncha
Suborder: Auchenorrhyncha
Order: Hemiptera
Suborder: Gymnocerata
Suborder: Cryptocerata
Order: Thysanoptera
Suborder: Tubulifera
Suborder: Terebrantia
Order: Anoplura
Order: Mallophaga

continued

Appendix II. TAXONOMIC CLASSIFICATION: LIVING ANIMALS

Order: Zoraptera
Order: Psocoptera
Suborder: Eupsocida
Suborder: Troctomorpha
Suborder: Trogiomorpha
Order: Embioptera
Order: Dermaptera
Order: Plecoptera
Order: Isoptera
Order: Orthoptera
Suborder: Grylloblattodea
Suborder: Blattodea
Suborder: Mantodea
Suborder: Phasmatodea
Suborder: Ensifera
Suborder: Caelifera
Order: Odonata
Suborder: Zygoptera
Suborder: Anisoptera
Order: Ephemeroptera
Subclass: Apterygota
Order: Collembola
Suborder: Symphypleona
Suborder: Arthropleona
Order: Thysanura
Suborder: Entotrophi
Suborder: Ectognatha
Order: Protura
Class: **Symphyla** [4]
Class: **Chilopoda** [4]
Subclass: Anamorpha
Order: Scutigeromorpha
Order: Heterostigmata
Suborder: Craterostigmomorpha
Suborder: Lithobiomorpha
Subclass: Epimorpha
Order: Scolopendromorpha
Order: Geophilomorpha
Class: **Diplopoda** [4]
Subclass: Chilognatha
Superorder: Colobognatha
Superorder: Helminthomorpha
Order: Cambalida
Order: Spirostreptida
Order: Spirobolida
Order: Julida
Order: Polydesmida
Order: Stemmiulida
Order: Nematophora
Superorder: Pentazonia
Order: Glomeridesmida
Order: Glomerida
Subclass: Pselaphognatha
Order: Polyxenida
Class: **Pauropoda** [4]
Class: **Onychophora** [4]

Phylum: **ANNELIDA** [4]

Class: **Archiannelida**
Class: **Hirudinea**
Order: Gnathobdellida
Order: Rhynchobdellida
Order: Acanthobdellida
Class: **Oligochaeta**
Class: **Myzostomaria**
Class: **Polychaeta**

Phylum: **ECHIUROIDEA** [4]

Order: Heteromyota
Order: Xenopneusta
Order: Echiuroinea

Phylum: **SIPUNCULOIDEA** [4]

Phylum: **MOLLUSCA** [4]

Class: **Cephalopoda**
Order: Dibranchia
Suborder: Octopoda
Suborder: Vampyromorpha
Suborder: Decapoda
Order: Tetrabranchia
Class: **Bivalvia**
Order: Septibranchia
Order: Eulamellibranchia
Order: Filibranchia
Order: Protobranchia
Class: **Scaphopoda**
Class: **Gastropoda**
Subclass: Pulmonata
Order: Stylommatophora
Order: Basommatophora
Subclass: Opisthobrancbia
Order: Acoela
Suborder: Nudibranchia
Suborder: Notaspidea
Order: Sacoglossa
Order: Pteropoda
Order: Pleurocoela
Subclass: Prosobranchia
Order: Stenoglossa
Order: Mesogastropoda
Order: Archaeogastropoda
Class: **Monoplacophora**
Order: Tryblidiacea
Class: **Aplacophora**
Order: Chaetodermomorpha
Order: Neomeniomorpha
Class: **Polyplacophora**
Order: Chitonida
Order: Lepidopleurida

Phylum: **BRACHIOPODA** [4]

Class: **Articulata**
Suborder: Terebratelloidea
Suborder: Terebratuloidea
Suborder: Rhynchonelloidea
Suborder: Thecideoidea
Class: **Inarticulata**
Order: Neotremata
Order: Atremata

Phylum: **PHORONIDA** [4]

Phylum: **POLYZOA** [4]

Class: **Gymnolaemata**
Order: Ctenostomata
Order: Cheilostomata
Order: Cyclostomata
Class: **Phylactolaemata**

Phylum: **ENTOPROCTA** [4]

Family: Urnatellidae
Family: Pedicellinidae
Family: Loxosomatidae

Phylum: **ACANTHOCEPHALA** [4]

Order: Eoacanthocephala
Order: Palaeacanthocephala
Order: Archiacanthocephala

Phylum: **ASCHELMINTHES** [4]

Class: **Nematoda**
Subclass: Aphasmidia
Order: Enoplida
Suborder: Dioctophymatina
Suborder: Dorylaimina
Suborder: Enoplina
Order: Chromadorida
Subclass: Phasmidia
Order: Spirurida
Order: Tylenchida
Order: Rhabditida
Suborder: Ascaridina
Suborder: Strongylina
Suborder: Rhabditina
Class: **Nematomorpha**
Order: Gordioidea
Order: Nectonematoidea
Class: **Priapulida**
Class: **Echinoderida**
Class: **Gastrotricha**
Order: Chaetonotoidea
Order: Macrodasyoidea
Class: **Rotifera**
Order: Monogononta
Suborder: Collothecacea
Suborder: Flosculariacea
Suborder: Ploima
Order: Bdelloidea
Order: Seisonidea

Phylum: **NEMERTINA** [4]

Class: **Enopla**
Order: Bdellonemertina
Order: Hoplonemertina
Suborder: Polystylifera
Suborder: Monostylifera
Class: **Anopla**
Order: Heteronemertina
Order: Palaeonemertina

Phylum: **PLATYHELMINTHES** [4]

Class: **Cestoda**
Subclass: Eucestoda
Order: Pseudophyllidea
Order: Nippotaeniidea
Order: Caryophyllidea
Order: Cyclophyllidea
Order: Trypanorhyncha
Order: Diphyllidea
Order: Disculicepitidea
Order: Lecanicephala
Order: Tetraphyllidea
Order: Proteocephala
Subclass: Cestodaria
Order: Gyrocotylidea
Order: Amphilinidea
Class: **Trematoda**
Order: Digenea
Suborder: Prosostomata
Suborder: Gasterostomata
Order: Aspidogastrea
Order: Monogenea
Suborder: Polyopisthocotylea
Suborder: Monopisthocotylea
Class: **Turbellaria**
Order: Polycladida
Suborder: Cotylea

continued

Appendix II. TAXONOMIC CLASSIFICATION: LIVING ANIMALS

Suborder: Acotylea
Order: Tricladida
Suborder: Terricola
Suborder: Paludicola
Suborder: Maricola
Order: Alloeocoela
Order: Rhabdocoela
Order: Acoela

Phylum: **CTENOPHORA** [4]

Class: **Nuda**
Order: Beroida
Class: **Tentaculata**
Order: Platyctenea
Order: Cestida
Order: Lobata
Order: Cydippida

Phylum: **CNIDARIA** [4]

Class: **Anthozoa**
Subclass: Zoantharia
Order: Scleractinia
Order: Ptychodactiaria
Order: Actiniaria
Order: Corallimorpharia
Order: Zoanthiniaria
Subclass: Octocorallia
Order: Pennatulacea
Order: Gorgonacea
Order: Alcyonacea
Subclass: Ceriantipatharia
Order: Ceriantharia
Order: Antipatharia
Class: **Scyphozoa**
Order: Rhizostomae
Order: Semaeostomae
Order: Coronatae
Order: Cubomedusae
Order: Stauromedusae
Class: **Hydrozoa**
Order: Siphonophora
Order: Narcomedusae
Order: Trachymedusae
Order: Limnomedusae
Order: Thecata
Order: Athecata

Phylum: **PORIFERA** [4]

Class: **Demospongiae**
Subclass: Keratosa
Subclass: Monaxonida
Order: Epipolasida
Order: Haplosclerina
Order: Poecilosclerina
Order: Halichondrina
Order: Hadromerina
Subclass: Tetractinellida
Order: Choristida
Order: Carnosa
Order: Myxospongida
Class: **Hexactinellida**
Order: Amphidiscophora
Order: Hexasterophora
Class: **Calcarea**
Order: Syconosa
Order: Asconosa

Phylum: **MESOZOA** [1]

Order: Orthonectida
Order: Dicyemida

Phylum: **PROTOZOA** [4]

Class: **Ciliata**
Subclass: Spirotricha
Order: Hypotrichida
Order: Ctenostomatida
Order: Entodiniomorphida
Order: Tintinnida
Order: Oligotrichida
Order: Heterotrichida
Suborder: Licnophorina
Suborder: Heterotrichina
Subclass: Holotricha
Order: Peritrichida
Order: Thigmotrichida
Order: Apostomatida
Order: Astomatida
Order: Hymenostomatida
Suborder: Pleuronematina
Suborder: Peniculina
Suborder: Tetrahymenina
Order: Trichostomatida
Order: Chonotrichida
Order: Suctorida
Order: Gymnostomatida
Suborder: Cyrtophorina
Suborder: Rhabdophorina
Class: **Cnidosporidia**
Order: Haplosporidia
Order: Actinomyxidia
Order: Microsporidia
Order: Myxosporidia
Class: **Sporozoa**
Subclass: Coccidiomorpha
Order: Eucoccidia
Suborder: Haemosporidia
Suborder: Eimeriidea
Suborder: Adeleidea
Order: Protococcidia
Subclass: Gregarinomorpha
Order: Schizogregarina
Order: Eugregarina
Order: Archigregarina
Class: **Actinopoda**
Order: Heliozoa
Order: Radiolaria
Class: **Rhizopoda**
Order: Foraminifera
Order: Testacea
Order: Amoebina
Order: Rhizomastigina
Class: **Mastigophora**
Subclass: Zoomastigina
Order: Opalinina
Order: Distomatina
Order: Metamonadina
Order: Protomonadina
Subclass: Phytomastigina
Order: Chrysomonadina
Order: Coccolithophorida
Order: Silicoflagellata
Order: Ebriideae
Order: Dinoflagellata
Order: Cryptomonadina
Order: Euglenoidina
Order: Chloromonadina
Order: Xanthomonadina
Order: Phytomonadina

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Appendix III. TAXONOMIC CLASSIFICATION: LIVING PLANTS

Part I. NONVASCULAR PLANTS

Phylum: **VIRA** [2]

Order: Virales
Order: Rickettsiales

Phylum: **BACTERIOPHYTA** [1,2]

Class: **Schizomycetes**
- Order: Pseudomonadales
- Order: Chlamydobacteriales
- Order: Hyphomicrobiales
- Order: Eubacteriales
- Order: Actinomycetales
- Order: Caryophanales
- Order: Beggiatoales
- Order: Myxobacterales
- Order: Spirochaetales
- Order: Mycoplasmatales
- *Incertis sedis*

Phylum: **MYXOPHYTA** [2]

Class: **Myxomyceteae**
- Order: Exosporales
- Order: Stemonitales
- Order: Liceales
- Order: Trichiales
- Order: Physarales
- Order: Hydromyxales

Class: **Acrasieae**
- Order: Acrasiales
- Order: Labyrinthulales

Class: **Plasmodiophoreae**
- Order: Plasmodiophorales

Phylum: **FUNGI** [2]

Class: **Phycomycetes**
- Order: Chytridiales
- Order: Hyphochytriales
- Order: Blastocladiales
- Order: Monoblepharidales
- Order: Saprolegniales
- Order: Lagenidiales
- Order: Peronosporales
- Order: Mucorales
- Order: Entomophthorales
- Order: Zoopagales
- Order: Eccrinales

Class: **Ascomycetes**
- Order: Endomycetales
- Order: Taphrinales
- Order: Plectascales
- Order: Myriangiales
- Order: Erysiphales
- Order: Dothideales
- Order: Pseudosphaeriales
- Order: Hemisphaeriales
- Order: Sphaeriales
- Order: Hypocreales
- Order: Clavicipitales
- Order: Pezizales
- Order: Helotiales
- Order: Hysteriales
- Order: Tuberales
- Order: Laboulbeniales

Class: **Basidiomycetes**
- Order: Uredinales
- Order: Ustilaginales
- Order: Auriculariales
- Order: Dacrymycetales
- Order: Tremellales
- Order: Tulasnellales
- Order: Polyporales
- Order: Agaricales
- Order: Protogastrales
- Order: Hymenogastrales
- Order: Phallales
- Order: Sclerodermatales
- Order: Nidulariales
- Order: Sphaerobolales
- Order: Lycoperdales

Class: **Fungi Imperfecti**
- Order: Sphaeropsidales
- Order: Melanconiales
- Order: Moniliales
- *Incertis sedis*
  - Mycelia sterilia

Phylum: **LICHENES** [2,3]

Class: **Phycolichenes**
- Order: Geosiphonales

Class: **Ascolichenes**
- Order: Verrucariales
- Order: Pyrenulales
- Order: Pyrenidiales
- Order: Dermatinales
- Order: Caliciales
- Order: Graphidiales
- Order: Roccellales
- Order: Thelotrematales
- Order: Cyanophilales
- Order: Lecidiales
- Order: Lecanorales
- Order: Caloplacales

Class: **Basidiolichenes**
- Order: Corales

Class: **Lichenes Imperfecti**

Phylum: **ALGAE** [3]

Division: CYANOPHYTA
- Class: **Cyanophyceae**
  - Order: Chroococcales
  - Order: Pleurocapsales
  - Order: Chamaesiphonales
  - Order: Hormogonales
    - Suborder: Nostocinales
    - Suborder: Stigonematinales

Division: EUGLENOPHYTA
- Class: **Euglenophyceae**
  - Order: Euglenales
    - Suborder: Eugleninales
    - Suborder: Colaciinales

Division: PYRROPHYTA
- Class: **Cryptophyceae**
  - Order: Monomastigales
  - Order: Cryptomonadales
  - Order: Phaeocapsales
  - Order: Cryptococcales
- Class: **Chloromonadophyceae**
  - Order: Chloromonadales
- Class: **Desmokontae**
  - Order: Desmomonadales
  - Order: Prorocentrales
  - Order: Dinophysalidales
  - Order: Desmocapsales
- Class: **Dinophyceae**
  - Subclass: Dinoflagellatae
    - Order: Gymnodiniales
    - Order: Blastodiniales
    - Order: Peridiniales
  - Subclass: Phytodiniformes
    - Order: Rhizodiniales
    - Order: Dinocapsales
    - Order: Dinococcales
    - Order: Dinotrichales

Division: CHRYSOPHYTA
- Class: **Heterokontae**
  - Order: Heterochloridales
  - Order: Rhizochloridales
  - Order: Heterocapsales
  - Order: Heterococcales
  - Order: Heterotrichales
  - Order: Heterosiphonales
- Class: **Chrysophyceae**
  - Order: Chrysomonadales
    - Suborder: Chromulininales
    - Suborder: Isochrysidinales
    - Suborder: Ochromonadinales
  - Order: Silicoflagellatae
    - Suborder: Siphonotestinales
    - Suborder: Stereotestinales
  - Order: Rhizochrysidales
  - Order: Chrysocapsales
  - Order: Chrysosphaerales
  - Order: Chrysotrichales
- Class: **Bacillariophyceae**
  - Subclass: Centricae
    - Order: Discales
    - Order: Soleniales
    - Order: Biddulphiales
  - Subclass: Pennatae
    - Order: Araphidales
    - Order: Raphidioidales
    - Order: Monoraphidales
    - Order: Biraphidales

Division: CHLOROPHYTA
- Class: **Chlorophyceae**
  - Order: Chlorochytridiales
  - Order: Volvocales
    - Suborder: Chlamydomonadinales
    - Suborder: Tetrasporinales
    - Suborder: Chlorodendrinales
  - Order: Chlorococcales
  - Order: Ulotrichales
    - Suborder: Ulotrichinales
    - Suborder: Ulvinales
    - Suborder: Schizogoniinales
    - Suborder: Sphaeropleinales
  - Order: Chaetophorales
  - Order: Cladophorales
  - Order: Oedogoniales
  - Order: Conjugatae
    - Suborder: Euconjugatae
    - Suborder: Desmidiinales
  - Order: Siphonales

Division: CHAROPHYTA
- Class: **Charophyceae**
  - Order: Charales

continued

Appendix III. TAXONOMIC CLASSIFICATION: LIVING PLANTS

Part I. NONVASCULAR PLANTS

Division: PHAEOPHYTA
Class: **Isogeneratae**
Order: Ectocarpales
Order: Sphacelariales
Order: Cutleriales
Order: Tilopteridales
Order: Dictyotales
Class: **Heterogeneratae**
Subclass: Haplostichidae
Order: Chordariales
Order: Sporochnales
Order: Desmarestiales
Subclass: Polystichidae
Order: Dictyosiphonales
Order: Laminariales
Class: **Cyclosporeae**
Order: Fucales
Division: RHODOPHYTA
Class: **Bangiophyceae**
Order: Porphyridiales
Order: Goniotrichales
Order: Bangiales
Order: Compsopogonales
Order: Rhodochaetales
Class: **Florideae**
Order: Nemalionales
Order: Gelidiales
Order: Cryptonemiales
Order: Gigartinales
Order: Rhodymeniales
Order: Ceramiales

Phylum: **BRYOPHYTA** [2]

Class: **Musci**
Order: Sphagnales
Order: Andreaeales
Order: Archidiales
Order: Dicranales
Order: Fissidentales
Order: Pottiales
Order: Grimmiales
Order: Funariales
Order: Schistostegales
Order: Tetraphidales
Order: Eubryales
Order: Isobryales
Order: Hookeriales
Order: Hypnobryales
Order: Buxbaumiales
Order: Polytrichales
Order: Dawsoniales
Class: **Hepaticae**
Order: Jungermaniales
Order: Calobryales
Order: Acrogynales
Order: Sphaerocarpales
Order: Marchantiales
Class: **Anthocerotae**
Order: Anthocerotales

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Part II. VASCULAR PLANTS

Phylum: **PTERIDOPHYTA** [1,2]

Class: **Psilopsida**
Order: Psilotales
Family: Psilotaceae
Class: **Lycopsida**
Order: Lycopodiales
Family: Lycopodiaceae
Order: Selaginellales
Family: Selaginellaceae
Order: Isoetales
Family: Isoetaceae
Class: **Sphenopsida**
Order: Equisetales
Family: Equisetaceae
Class: **Pteropsida**
Subclass: Eusporangiatae
Order: Ophioglossales
Family: Ophioglossaceae
Order: Marattiales
Family: Marattiaceae
Subclass: Osmundidae
Order: Osmundales
Family: Osmundaceae
Subclass: Leptosporangiatae
Order: Filicales
Family: Aspidiaceae
Family: Aspleniaceae
Family: Blechnaceae
Family: Cyatheaceae
Family: Davalliaceae
Family: Dicksoniaceae
Family: Gleicheniaceae
Family: Hymenophyllaceae
Family: Hymenophyllopsidaceae
Family: Loxsomaceae
Family: Matoniaceae
Family: Parkeriaceae
Family: Plagiogyriaceae
Family: Polypodiaceae
Family: Pteridaceae
Family: Schizaeaceae
Family: Vittariaceae
Order: Marsileales
Family: Marsileaceae
Order: Salviniales
Family: Salviniaceae

Phylum: **SPERMATOPHYTA** [1]

Class: **Gymnospermae**
Order: Pinales
Family: Araucariaceae
Family: Cephalotaxaceae
Family: Cupressaceae
Family: Pinaceae
Family: Podocarpaceae
Family: Taxodiaceae
Order: Taxales
Family: Taxaceae
Order: Ginkgoales
Family: Ginkgoaceae
Order: Gnetales
Family: Ephedraceae
Family: Gnetaceae
Family: Welwitschiaceae
Order: Cycadales
Family: Cycadaceae
Class: **Angiospermae**
Subclass: Monocotyledoneae
Order: Pandanales
Family: Pandanaceae
Family: Sparganiaceae
Family: Typhaceae
Order: Najadales
Family: Alismataceae
Family: Aponogetonaceae
Family: Butomaceae
Family: Hydrocharitaceae
Family: Lilaeaceae
Family: Najadaceae
Family: Potamogetonaceae
Family: Scheuchzeriaceae
Order: Triuridales
Family: Triuraceae
Order: Graminales
Family: Gramineae
Order: Cyperales
Family: Cyperaceae
Order: Palmales
Family: Palmae
Order: Cyclanthales
Family: Cyclanthaceae
Order: Arales
Family: Araceae
Family: Lemnaceae

continued

Appendix III. TAXONOMIC CLASSIFICATION: LIVING PLANTS

Part II. VASCULAR PLANTS

- Order: Farinosae
  - Family: Bromeliaceae
  - Family: Centrolepidaceae
  - Family: Commelinaceae
  - Family: Cyanastraceae
  - Family: Eriocaulaceae
  - Family: Flagellariaceae
  - Family: Mayacaceae
  - Family: Philydraceae
  - Family: Pontederiaceae
  - Family: Rapateaceae
  - Family: Restionaceae
  - Family: Thurniaceae
  - Family: Xyridaceae
- Order: Liliales
  - Family: Amaryllidaceae
  - Family: Dioscoreaceae
  - Family: Haemodoraceae
  - Family: Iridaceae
  - Family: Juncaceae
  - Family: Liliaceae
  - Family: Stemonaceae
  - Family: Taccaceae
  - Family: Velloziaceae
- Order: Zingiberales
  - Family: Cannaceae
  - Family: Marantaceae
  - Family: Musaceae
  - Family: Zingiberaceae
- Order: Orchidales
  - Family: Burmanniaceae
  - Family: Orchidaceae

Subclass: Dicotyledoneae

- Order: Casuarinales
  - Family: Casuarinaceae
- Order: Piperales
  - Family: Chloranthaceae
  - Family: Piperaceae
  - Family: Saururaceae
- Order: Hydrostachyales
  - Family: Hydrostachyaceae
- Order: Salicales
  - Family: Salicaceae
- Order: Garryales
  - Family: Garryaceae
- Order: Myricales
  - Family: Myricaceae
- Order: Balanopsidales
  - Family: Balanopaceae
- Order: Leitneriales
  - Family: Leitneriaceae
- Order: Juglandales
  - Family: Juglandaceae
- Order: Julianales
  - Family: Julianiaceae
- Order: Batidales
  - Family: Bataceae
- Order: Fagales
  - Family: Betulaceae
  - Family: Fagaceae
- Order: Urticales
  - Family: Moraceae
  - Family: Rhoipteleaceae
  - Family: Ulmaceae
  - Family: Urticaceae
- Order: Podostemales
  - Family: Podostemaceae
- Order: Proteales
  - Family: Proteaceae
- Order: Santalales
  - Family: Grubbiaceae
  - Family: Loranthaceae
  - Family: Misodendraceae
  - Family: Octoknemaceae
  - Family: Olacaceae
  - Family: Opiliaceae
  - Family: Santalaceae
- Order: Aristolochiales
  - Family: Aristolochiaceae
  - Family: Hydnoraceae
  - Family: Rafflesiaceae
- Order: Balanophorales
  - Family: Balanophoraceae
- Order: Polygonales
  - Family: Polygonaceae
- Order: Caryophyllales
  - Family: Achatocarpaceae
  - Family: Aizoaceae
  - Family: Amaranthaceae
  - Family: Basellaceae
  - Family: Caryophyllaceae
  - Family: Chenopodiaceae
  - Family: Gyrostemonaceae
  - Family: Nyctaginaceae
  - Family: Phytolaccaceae
  - Family: Portulacaceae
- Order: Ranales
  - Family: Annonaceae
  - Family: Berberidaceae
  - Family: Calycanthaceae
  - Family: Ceratophyllaceae
  - Family: Cercidiphyllaceae
  - Family: Degeneriaceae
  - Family: Eupomatiaceae
  - Family: Eupteleaceae
  - Family: Gomortegaceae
  - Family: Hernandiaceae
  - Family: Himantandraceae
  - Family: Illiciaceae
  - Family: Lactoridaceae
  - Family: Lardizabalaceae
  - Family: Lauraceae
  - Family: Magnoliaceae
  - Family: Menispermaceae
  - Family: Monimiaceae
  - Family: Myristicaceae
  - Family: Nymphaeaceae
  - Family: Ranunculaceae
  - Family: Schisandraceae
  - Family: Tetracentraceae
  - Family: Trochodendraceae
  - Family: Winteraceae
- Order: Rhoeadales
  - Family: Bretschneideraceae
  - Family: Capparaceae
  - Family: Cruciferae
  - Family: Fumariaceae
  - Family: Moringaceae
  - Family: Papaveraceae
  - Family: Resedaceae
  - Family: Tovariaceae
- Order: Sarraceniales
  - Family: Droseraceae
  - Family: Nepenthaceae
  - Family: Sarraceniaceae
- Order: Rosales
  - Family: Brunelliaceae
  - Family: Bruniaceae
  - Family: Byblidaceae
  - Family: Cephalotaceae
  - Family: Connaraceae
  - Family: Crassulaceae
  - Family: Crossosomataceae
  - Family: Cunoniaceae
  - Family: Eucommiaceae
  - Family: Hamamelidaceae
  - Family: Leguminosae
  - Family: Myrothamnaceae
  - Family: Pittosporaceae
  - Family: Platanaceae
  - Family: Rosaceae
  - Family: Saxifragaceae
- Order: Pandales
  - Family: Pandaceae
- Order: Geraniales
  - Family: Burseraceae
  - Family: Callitrichaceae
  - Family: Cneoraceae
  - Family: Daphniphyllaceae
  - Family: Dichapetalaceae
  - Family: Erythroxylaceae
  - Family: Euphorbiaceae
  - Family: Geraniaceae
  - Family: Linaceae
  - Family: Malpighiaceae
  - Family: Meliaceae
  - Family: Oxalidaceae
  - Family: Polygalaceae
  - Family: Rutaceae
  - Family: Simaroubaceae
  - Family: Tremandraceae
  - Family: Trigoniaceae
  - Family: Tropaeolaceae
  - Family: Vochysiaceae
  - Family: Zygophyllaceae
- Order: Sapindales
  - Family: Aceraceae
  - Family: Aextoxicaceae
  - Family: Anacardiaceae
  - Family: Aquifoliaceae
  - Family: Balsaminaceae
  - Family: Buxaceae
  - Family: Celastraceae
  - Family: Coriariaceae
  - Family: Corynocarpaceae
  - Family: Cyrillaceae
  - Family: Didiereaceae
  - Family: Empetraceae
  - Family: Hippocastanaceae
  - Family: Icacinaceae
  - Family: Limnanthaceae
  - Family: Melianthaceae
  - Family: Pentaphylacaceae
  - Family: Sabiaceae
  - Family: Salvadoraceae
  - Family: Sapindaceae

continued

Appendix III. TAXONOMIC CLASSIFICATION: LIVING PLANTS

Part II. VASCULAR PLANTS

Family: Stackhousiaceae
Family: Staphyleaceae
Order: Rhamnales
Family: Rhamnaceae
Family: Vitaceae
Order: Malvales
Family: Bombacaceae
Family: Elaeocarpaceae
Family: Malvaceae
Family: Sarcolaenaceae
Family: Scytopetalaceae
Family: Sterculiaceae
Family: Tiliaceae
Order: Parietales
Family: Achariaceae
Family: Actinidiaceae
Family: Ancistrocladaceae
Family: Begoniaceae
Family: Bixaceae
Family: Canellaceae
Family: Caricaceae
Family: Caryocaraceae
Family: Cistaceae
Family: Cochlospermaceae
Family: Datiscaceae
Family: Dilleniaceae
Family: Dipterocarpaceae
Family: Elatinaceae
Family: Eucryphiaceae
Family: Flacourtiaceae
Family: Frankeniaceae
Family: Guttiferae
Family: Hypericaceae
Family: Loasaceae
Family: Malesherbiaceae
Family: Marcgraviaceae
Family: Medusagynaceae
Family: Ochnaceae
Family: Passifloraceae
Family: Quiinaceae
Family: Stachyuraceae
Family: Strasburgeriaceae
Family: Tamaricaceae
Family: Theaceae
Family: Turneraceae
Family: Violaceae
Order: Opuntiales
Family: Cactaceae

Order: Myrtales
Family: Alangiaceae
Family: Combretaceae
Family: Crypteroniaceae
Family: Cynomoriaceae
Family: Elaeagnaceae
Family: Geissolomataceae
Family: Haloragaceae
Family: Heteropyxidaceae
Family: Hippuridaceae
Family: Lecythidaceae
Family: Lythraceae
Family: Melastomataceae
Family: Myrtaceae
Family: Nyssaceae
Family: Oliniaceae
Family: Onagraceae
Family: Penaeaceae
Family: Punicaceae
Family: Rhizophoraceae
Family: Sonneratiaceae
Family: Theligonaceae
Family: Thymelaeaceae
Family: Trapaceae
Order: Umbellales
Family: Araliaceae
Family: Cornaceae
Family: Umbelliferae
Order: Diapensiales
Family: Diapensiaceae
Order: Ericales
Family: Clethraceae
Family: Epacridaceae
Family: Ericaceae
Family: Pyrolaceae
Order: Primulales
Family: Myrsinaceae
Family: Primulaceae
Family: Theophrastaceae
Order: Plumbaginales
Family: Plumbaginaceae
Order: Ebenales
Family: Diclidantheraceae
Family: Ebenaceae
Family: Hoplestigmataceae
Family: Lissocarpaceae
Family: Sapotaceae
Family: Styracaceae

Family: Symplocaceae
Order: Gentianales
Family: Apocynaceae
Family: Asclepiadaceae
Family: Desfontainiaceae
Family: Gentianaceae
Family: Loganiaceae
Family: Oleaceae
Order: Tubiflorae
Family: Acanthaceae
Family: Bignoniaceae
Family: Boraginaceae
Family: Columelliaceae
Family: Convolvulaceae
Family: Fouquieriaceae
Family: Gesneriaceae
Family: Globulariaceae
Family: Hydrophyllaceae
Family: Labiatae
Family: Lennoaceae
Family: Lentibulariaceae
Family: Martyniaceae
Family: Myoporaceae
Family: Nolanaceae
Family: Orobanchaceae
Family: Pedaliaceae
Family: Phrymaceae
Family: Polemoniaceae
Family: Scrophulariaceae
Family: Solanaceae
Family: Verbenaceae
Order: Plantaginales
Family: Plantaginaceae
Order: Rubiales
Family: Adoxaceae
Family: Caprifoliaceae
Family: Dipsacaceae
Family: Rubiaceae
Family: Valerianaceae
Order: Cucurbitales
Family: Cucurbitaceae
Order: Campanulatae
Family: Brunoniaceae
Family: Calyceraceae
Family: Campanulaceae
Family: Compositae
Family: Goodeniaceae
Family: Stylidiaceae

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Appendix IV. GEOLOGIC DISTRIBUTION: ANIMALS AND PLANTS

	Era (Duration, yr)	Period (Duration, yr) [Years Ago]	Epoch (Duration, yr) [Years Ago]	Advances in Life	Dominant Life
	(A)	(B)	(C)	(D)	(E)
1	Cenozoic (60 million)	Quaternary (2 million) [2 million]	Recent	Rise of civilization	Man and herbaceous plants
2			Pleistocene	Periodic glaciation; extinction of great mammals and many trees; rise of modern herbs; elevation of continents	Mammals, birds, and flowering plants
3		Tertiary (58 million) [60 million]	Pliocene	Continued cooling of climate; elevation of Andes; increasing restriction of plant distribution and forests; appearance of man	
4			Miocene	Greatly changing climate, becoming cool and semiarid; elevation of Alps; restriction of distribution of plants; beginning of forest reduction; culmination of many mammals	
5			Oligocene	Warm, humid climate; elevation of Pyrenees; culmination of Eocene floras; worldwide distribution of tropical forests; disappearance of primitive mammals; rise of higher mammals and birds	
6			Eocene	Cool climate, semiarid, then warm and humid; modernization of flowering plants; development of extensive forests, widespread in polar regions; appearance of modern birds and marine mammals	
7	Mesozoic (125 million)	Cretaceous (65 million) [125 million]	Upper Cretaceous	Fluctuating climate; angiosperms dominant in floras, dicotyledons, and monocotyledons of numerous existing genera well-developed; disappearance of Bennettitales; rise of primitive mammals	Reptiles and higher gymnosperms
8			Middle Cretaceous	Fluctuating climate; rapid development of angiosperms, appearance of many existing genera; specialization and extinction of great reptiles	
9			Lower Cretaceous	Very warm climate; rise of angiosperms (?); conifers and cycads still dominant; earliest known pines (Pinaceae)	
10		Jurassic (32 million) [157 million]	Jurassic	Warm climate; beginning of Sierra Nevada mountains; first definitely known angiosperms; conifers and cycads dominant; Ginkgoales and conifers worldwide; disappearance of cordaites; primitive birds and flying reptiles; rise of higher insects	
11		Triassic (28 million) [185 million]	Triassic	Warm, semiarid climate; nonluxuriant floras; increase in gymnosperms, spread of conifers, rise of cycads and Bennettitales; disappearance of seed ferns; diversification of modern fern families well under way; first mammals; rise of giant reptiles (dinosaurs)	
12	Paleozoic (368 million)	Carboniferous	Permian (38 million) [223 million]	Dry climate; periodic glaciation, severe in southern hemisphere; elevation of Appalachians; dwindling of ancient groups, extinction of many; rise of ferns and conifers and of land vertebrates; expansion of reptiles; Gondwana flora of southern hemisphere distinct from those in northern hemisphere	Amphibians, lycopods, and seed ferns
13			Pennsylvanian (48 million) [271 million]	Lycopods, seed ferns, and horsetails dominant; sphenophylls, Coniferales and calamites present; extensive coal formation	
14			Mississippian (38 million) [309 million]	Lycopods, horsetails, and seed ferns dominant; cordaites, sphenophylls, and calamites present; rise of primitive reptiles and insects	
15		Devonian (45 million) [354 million]	Devonian	Early land floras: Psilophytales (*Rhynia*, *Horneophyton*); lycopods; primitive horsetails, including sphenophylls; primitive gymnosperms (earliest cordaites and seed ferns, their seeds not yet known); first forests; rise of amphibians and fishes	Fishes and early land plants
16		Silurian (27 million) [381 million]	Silurian	Algae dominant (e.g., *Nematophyton hicksi*); rise of lungfishes and scorpions (first air-breathing animals)	Higher invertebrates and algae
17		Ordovician (67 million) [448 million]	Ordovician	Rise of corals, armored fishes (and land plants ?); marine algae dominant; first known freshwater fishes	
18		Cambrian (105 million) [553 million]	Cambrian	Warm climate, uniform over earth; first abundance of fossils; many groups of marine invertebrates; dominant trilobites; marine plants, few algae determinable; evidence from microfossils may indicate land plants	

continued

Appendix IV. GEOLOGIC DISTRIBUTION: ANIMALS AND PLANTS

	Era (Duration, yr)	Period (Duration, yr) [Years Ago]	Epoch	Advances in Life	Dominant Life
	(A)	(B)	(C)	(D)	(E)
19	Proterozoic (900 million)	Precambrian [1.5 billion]	Precambrian	Rocks chiefly sedimentary, and of enormous thickness; glaciation; first fossils: worms, crustaceans, brachiopods; evidence of algal and bacterial life	Primitive marine invertebrates (fossils rare)
20	Archeozoic (550+ million)	[3.5-5.0 billion]		Igneous rocks: lavas and metamorphosed rocks; few sedimentary; no direct evidence of life; graphites of possible organic origin in sedimentary rocks of Grenville series	Unicellular life? (fossils unknown)

Contributors: (a) Wetmore, Ralph H., (b) ZoBell, Claude E., (c) Eames, A. J., and Banks, Harlan P.

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Appendix V. FORMULAS, FACTORS, AND CONSTANTS

Part I. CONVERSION FORMULAS

mEq/L ⟷ mg/100 ml

$$\text{mEq/L} = \frac{\text{mg/100 ml} \times \text{valence} \times 10}{\text{atomic weight}}$$

$$\text{mg/100 ml} = \frac{\text{mEq/L} \times \text{atomic weight}}{\text{valence} \times 10}$$

mM/L ⟷ mg/100 g

$$\text{mM/L} = \frac{\text{mg/100 g} \times 10}{\text{atomic weight}}$$

$$\text{mg/100 g} = \frac{\text{mM/L} \times \text{atomic weight}}{10}$$

ml (milliliters) ⟷ g (grams)

$$\text{ml} = \frac{\text{g}}{\text{specific gravity}}$$

$$\text{g} = \text{ml} \times \text{specific gravity}$$

Wet basis ⟷ dry basis

$$\text{Wet basis} \rightarrow \text{dry basis} = \frac{100 \times a}{b}$$

$$\text{Dry basis} \rightarrow \text{wet basis} = \frac{a \times b}{100}$$

a = % of material determined (wet or dry)
b = % of dry sample (100 - c = b)
c = % moisture in sample

Temperature: $^{\circ}C \longleftrightarrow {^{\circ}F}$

$$^{\circ}C = (^{\circ}F - 32) \times 5/9$$

$$^{\circ}F = (^{\circ}C \times 9/5) + 32$$

continued

Appendix V. FORMULAS, FACTORS, AND CONSTANTS

Part II. CONVERSION FACTORS

Multiply the value for the unit of measurement in column A by the factor in column B to convert to the unit of measurement in column C.

Column A	x Column B	= Column C
Abamperes	10.0000	amperes
	2.99796×10^{10}	statamperes
Abcoulombs	10.0000	coulombs (abs.)
	2.99796×10^{10}	statcoulombs
Abcoulombs/kg	30,577	statcoulombs/dyne
Abcoulombs/lb	6.7411×10^{4}	statcoulombs/dyne
Abfarads	1.0000×10^{9}	farads (abs.)
	1×10^{15}	microfarads
	8.98776×10^{20}	statfarads
Abhenries	1.0000×10^{-9}	henries (abs.)
	1×10^{-6}	millihenries
	1.11263×10^{-21}	stathenries
Abmhos/cu cm	1,000	megmhos/cu cm
	1.00052×10^{9}	mhos (Int.)/cu cm
	166.2	mhos/million ft
Abohms	1×10^{-15}	megohms
	0.001	microhms
	1.0000×10^{-9}	ohms (abs.)
	1.11263×10^{-21}	statohms
Abvolts	0.010000	microvolts
	3.33560×10^{-1}	statvolts
	1.0000×10^{-8}	volts (abs.)
Abvolts/°F	0.018000	microvolts/°C
Abvolts/cm	1.0000×10^{-8}	volts (abs.)/cm
Abvolts/inch	3.9370×10^{-9}	volts (abs.)/cm
Acres (U.S.)	40.46873	ares
	0.4046873	hectares
	43,560	sq ft
	4,046.873	sq m
	0.0015625	sq mi
	160	sq rods
	4,840	sq yd
Ampere-hours (absolute)	3,600.0	coulombs (abs.)
Amperes (absolute)	0.1	abamperes
	1.00007	amperes (Int.)
	1.0363×10^{-5}	faradays/sec
	2.99796×10^{9}	statamperes
Angstrom units	3.937×10^{-9}	inches
	1×10^{-10}	meters
	100	micromicrons
	1×10^{-4}	microns
	0.1	millimicrons
Atmospheres	1.0133	bars
	1.01325×10^{6}	dynes/sq cm
	1,033.3	g/sq cm
	10,333	kg/sq m
	2,116.32	lb/sq ft
	14.696	lb/sq inch
	76	cm Hg at 0°C
	760	mm Hg
	760,000	microns Hg
	29.921	inches Hg at 32°F
	33.899	ft water at 39.1°F
Barrels (U.S., dry)	3.281	bushels
	7,056	cu inches
	0.11562	cu m
	105.0	quarts (dry)
Barrels (U.S., liquid)	0.11924	cu m
	31.5	gallons
BTU	252	gram calories
	25,030	ft-poundals

Column A	x Column B	= Column C
BTU	777.9	ft-lb
	3.929×10^{-4}	horsepower-hr
	1,055	joules
Bushels (U.S., dry)	0.304785	barrels
	35,239	cu cm
	1.2444	cu ft
	2,150.42	cu inches
	0.035239	cu m
	0.35238329	hectoliters
	35.238329	liters
	4	pecks
Bushels (U.S., dry)/acre	0.870754	Hectoliters/hectare
Calorie (15°C) sec	6.3854×10^{33}	quanta
Calorie (15°C) sec/N_0[1]	1.0535×10^{10}	quanta
Calories (15°C)/amp-hr	0.011625	joules/abcoulomb
Calories (15°C)/coulomb	41.850	joules/abcoulomb
Calories, gram	3.968×10^{-3}	BTU
	1.5591×10^{-6}	horsepower-hr
Calories, gram (mean)	0.001469	cu ft-atm
	99.334	ft-poundals
	3.0874	ft-lb
	0.42685	kg-m
	4.1311×10^{-2}	L-atm
	0.0011628	watt-hr
Calories, gram (mean)/g	1.8	BTU (mean)/lb
Calories, gram (mean)/g/°C	1	BTU (60°F)/lb/°F
	4.186	joules/g/°C
Calories, gram (15°C)	4.185	joules (abs.)
Calories, gram (15°C)/°C	0.0022046	BTU (60°F)/°F
	4.185	joules/°C
Calories, kilogram (mean)	3.9685	BTU (mean)
	1,000	gram calories (mean)
	4.186×10^{10}	ergs
	3,087.4	ft-lb
	4.2686×10^{7}	g-cm
	0.0015593	horsepower-hr
	4,186	joules
	426.85	kg-m
	0.0011628	kw-hr
Calories, kilogram (mean)/min	51.457	ft-lb/sec
	0.093558	horsepower
	69.769	watts
Calories, kilogram (mean)/sec	4.186	kilowatts
Candlepower (spherical)	12.566	lumens
Candles (International)	1.0000	lumens (Int.)/steradian
Candles/sq cm	3.1416	lamberts
Candles/sq inch	0.48695	lamberts
Centigrade thermal units (15°C)	1,898.3	joules (abs.)
Centimeters	1×10^{8}	angstrom units
	0.032808	feet (U.S. or British)
	0.393700	inches (U.S.)
	10,000	microns
	393.70	mils
	0.01093611	yards (U.S.)

/1/ Avogadro's number.

continued

Appendix V. FORMULAS, FACTORS, AND CONSTANTS

Part II. CONVERSION FACTORS

Column A	x Column B	= Column C
Centimeters/sec	1.9685	ft/min
	0.03600	km/hr
	0.6000	m/min
	0.02237	mi/hr
	3.728×10^{-4}	mi/min
Centimeters/sec/sec	0.036	km/hr/sec
	0.02237	mi/hr/sec
Centimeters mercury at 0°C	0.013158	atmospheres
	1.33322×10^{4}	dynes/sq cm
	135.95	kg/sq m
	27.845	lb/sq ft
	0.19337	lb/sq inch
	0.44604	ft water at 39.1°F
Circles	6.28319	radians
Circular inches	5.0671	sq cm
	0.78540	sq inches
Circular millimeters	0.78540	sq mm
Circumferences	400	grades
Coulombs (abs.)	0.1000	abcoulombs or electromagnetic cgs units
	1.00010	coulombs (Int.)
	6.281×10^{18}	electronic charges
	2.99796×10^{9}	electrostatic cgs units or statcoulombs
Coulombs (International)	0.99990	coulombs (abs.)
Coulombs/kg	3,057.7	statcoulombs/dyne
Cubic centimeter-atmospheres (normal)	0.101325	joules (abs.)
Cubic centimeters	3.531445×10^{-5}	cu ft (U.S.)
	0.061023	cu inches
	1.3079×10^{-6}	cu yd
	0.27053	drams (U.S., fluid)
	2.6417×10^{-4}	gallons (U.S.)
	9.9997×10^{-4}	liters
	16.231	minims (U.S.)
	0.033814	ounces (U.S., fluid)
	0.0021134	pints (U.S., liquid)
	9.0808×10^{-4}	quarts (U.S., dry)
	0.0010567	quarts (U.S., liquid)
Cubic centimeters/sec	0.0021186	cu ft/min
Cubic feet (U.S.)	28,317	cu cm
	1,728	cu inches
	0.02831701	cu m
	0.037037	cu yd
	7.481	gallons (U.S.)
	28.316	liters
	25.714	quarts (U.S., dry)
	29.922	quarts (U.S., liquid)
Cubic feet/min	472.0	cu cm/sec
	0.1247	gal/sec
	0.4720	L/sec
Cubic feet/sec	2.22222	cu yd/min
Cubic feet water at 60°F	62.37	pounds
Cubic foot-atmospheres	680.74	gram calories (mean)
	2,116.3	ft-lb
	2,869.4	joules (abs.)
	292.59	kg-m
	28.316	L-atm
Cubic inches (U.S.)	16.387162	cu cm
	5.78704×10^{-4}	cu ft (U.S.)

Column A	x Column B	= Column C
Cubic inches (U.S.)	1.63871×10^{-5}	cu m
	2.143347×10^{-5}	cu yards
	4.43322	drams (fluid)
	0.0043290	gallons (U.S.)
	0.0163868	liters
	0.5541	ounces (U.S., fluid)
	0.00186010	pecks (U.S.)
	0.0297616	pints (U.S., dry)
	0.0148808	quarts (U.S., dry)
	0.017316	quarts (U.S., liquid)
	4.65025×10^{-4}	bushels (U.S.)
Cubic inches (British)	16.3870253	cu cm
	5.7870×10^{-4}	cu ft (British)
Cubic kilometers	1×10^{9}	cu m
Cubic meters	28.3776	bushels (U.S.)
	1×10^{6}	cu cm
	35.314445	cu ft (U.S.)
	61,023	cu inches
	1.3079428	cu yd (U.S.)
	999.973	liters
	2,113.4	pints (U.S., liquid)
	1,056.7	quarts (U.S., liquid)
Cubic millimeters	6.1023×10^{-5}	cu inches
	1×10^{-9}	cu m
	0.016231	minims (U.S.)
Cubic yards	764,559.45	cu cm
	764.54	liters
Cubic yards (U.S.)	27	cu ft
	46,656	cu inches
	0.76455945	cu m
	202.0	gallons (U.S.)
	1,616	pints (U.S., liquid)
	807.9	quarts (U.S., liquid)
Days (mean solar)	24	hours (mean solar)
	1,440	minutes (mean solar)
	86,400	seconds (mean solar)
Days (siderial)	86,164	seconds (mean solar)
Degrees	0.00277778	circumferences
	60	minutes
	1/90	quadrants
	0.0174533	radians
	0.00277778	revolutions
	3,600	seconds
Degrees/sec	0.1667	revolutions/min
	0.002778	revolutions/sec
Drams (apothecary or troy)	2.194286	drams (avoir.)
	60	grains
	3.8879351	grams
	0.1371429	ounces (avoir.)
	0.125	ounces (troy)
	2.5	pennyweights
	0.008571429	pounds (avoir.)
	1/96	pounds (troy)
Drams (avoirdupois)	0.4557292	drams (apoth. or troy)
	27.34375	grains
	1.771845	grams
	0.0625	ounces (avoir.)
	0.056966146	ounces (troy)
	1/256	pounds (avoir.)
	0.0047471788	pounds (troy)
Drams (U.S., fluid or apothecary)	3.6967	cu cm
	0.225570	cu inches
	3.6966	milliliters
	60	minims (U.S., fluid)
	0.125	ounces (fluid)
Dyne-centimeters (torque)	1.0197×10^{-8}	kg-m
	7.3757×10^{-8}	lb-ft
	8.8511×10^{-7}	lb-inches

continued

Appendix V. FORMULAS, FACTORS, AND CONSTANTS

Part II. CONVERSION FACTORS

Column A	x Column B	= Column C
Dynes	0.015368	grains
	0.00101972	grams
	2.2481×10^{-6}	pounds
Dynes/cm	1	ergs/sq cm
	0.01	ergs/sq mm
	2.5901	mg/inch
	0.10197	mg/mm
Dynes/sq cm	9.8692×10^{-7}	atmospheres
	0.0101971	kg/sq m
	0.0020886	lb/sq ft
	1.4504×10^{-5}	lb/sq inch
	7.5006×10^{-4}	mm Hg
	2.9530×10^{-5}	inches Hg at 32°F
	4.0148×10^{-4}	inches water at 39.2°F (4°C)
Electromagnetic cgs units of field strength	1.0000	gauss (abs.)
Electromagnetic cgs units of magnetic permeability	8.9916×10^{20}	electrostatic cgs units of magnetic permeability
Electromagnetic cgs units of mass resistance	9.9948×10^{-6}	ohm (Int.)-meter-gram
Electromagnetic cgs units of reluctance	1.0000	oersteds (abs.)
Electronic charges	1.5921×10^{-20}	abcoulombs
	1.5921×10^{-19}	coulombs (abs.)
	4.774×10^{-10}	statcoulombs
Electrons/kg	4.868×10^{-16}	statcoulombs/dyne
Electrostatic cgs units of field strength	3.33560×10^{-11}	gauss (abs.)
Ergs	9.4805×10^{-11}	BTU (mean)
	2.3889×10^{-8}	gram calories (mean)
	2.3889×10^{-11}	kg calories (mean)
	7.3756×10^{-8}	ft-lb
	0.00101972	g-cm
	1×10^{-7}	joules
	1.0197×10^{-8}	kg-m
Ergs/sec	5.6883×10^{-9}	BTU (mean)/min
	1.4333×10^{-9}	kg calories (mean)/min
	4.4254×10^{-6}	ft-lb/min
	7.3756×10^{-8}	ft-lb/sec
	1.3410×10^{-10}	horsepower
	1×10^{-10}	kilowatts
	1×10^{-7}	watts
Ergs/sq cm	1	dynes/cm
	0.01	ergs/sq mm
	100	dynes/cm
	100	ergs/sq cm
Faradays	9.6500×10^{4}	coulombs (abs.)
	9.6507×10^{4}	coulombs (Int.)
Faradays/kg	2.9507×10^{8}	statcoulombs/dyne
Faradays/sec	96,500	amperes (abs.)
Farads (abs.)	1×10^{-9}	abfarads
	1.00052	farads (Int.)
	1×10^{6}	microfarads
	8.98776×10^{11}	statfarads
Farads (International)	0.99948	farads (abs.)
Fathoms	6	fect
Feet (U.S.)	30.48006096	centimeters
	0.3048006096	meters
Feet (U.S.)	1.6447×10^{-4}	miles (nautical)
	1.893939×10^{-4}	miles (statute)
	473.404	wavelengths of cadmium red line
Feet/min	0.508001	cm/sec
	0.01829	km/hr
	0.00508001	mi/sec
	0.011364	m/hr
Feet/sec	1.0973	km/hr
	0.5921	knots/hr
	18.29	m/min
	0.6818	mi/hr
	0.011364	mi/min
Feet/sec/sec	1.0973	km/hr/sec
Feet water at 39.2°F (4°C)	0.029499	atmospheres
	304.79	kg/sq m
	0.43352	lb/sq inch
	62.427	lb/sq ft
	0.88265	inches Hg at 32°F (0°C)
Foot-pounds	0.32389	gram calories (mean)
	4.7253×10^{-4}	cu ft-atm
	1.35582×10^{7}	ergs
	1.3825×10^{4}	g-cm
	5.0505×10^{-7}	horsepower-hr
	1.35582	joules (abs.)
	0.138255	kg-m
	3.7662×10^{-7}	kw-hr
	0.013381	L-atm
Foot-pounds/min	2.2597×10^{-5}	kilowatts
Foot-pounds/sec	0.0018182	horsepower
	0.00135582	kilowatts
	1.35582	watts (abs.)
Footcandles	10.764	lumens/sq m
Gallons (U.S.)	3,785.4	cu cm
	0.13368	cu ft
	231	cu inches
	0.0037854	cu m
	0.004951	cu yd
	3.78533	liters
	61,440	minims
	128	ounces (U.S., fluid)
	8	pints (U.S., liquid)
	4	quarts (U.S., liquid)
	8.3378	pounds (avoir.) water at 62°F (16.7°C)
Gallons (U.S.)/min	8.0208	cu ft/hr
	0.002228	cu ft/sec
	0.06308	liters/sec
Gallons (U.S.) water/min	6.0086	tons water/24 hr
Grains	63.5453	dynes
	0.064798918	grams
	64.798918	milligrams
	0.0022857	ounces (avoir.)
	0.0020833	ounces (troy)
	1/7000	pounds (avoir.)
	1/5760	pounds (troy)
Gram-centimeters	2.3427×10^{-5}	gram calories (mean)
	980.665	ergs
	7.233×10^{-5}	ft-lb
	9.80665×10^{-5}	joules (abs.)
	1×10^{-5}	kg-m
Gram-centimeters/sec	9.80665×10^{-5}	watts (abs.)
Gram-square centimeters (moment of inertia)	2.37305×10^{-6}	lb/sq ft
	3.4172×10^{-4}	lb/sq inch

continued

Part II. CONVERSION FACTORS

Column A	x Column B	= Column C
Grams	980.665	dynes
	15.4324	grains
	1×10^{6}	micrograms
	1,000	milligrams
	0.0352739	ounces (avoir.)
	0.0321507	ounces (troy)
	0.00220462	pounds (avoir.)
	0.00267923	pounds (troy)
	1×10^{-6}	tons (metric)
Grams/cu cm	62.43	lb/cu ft
	0.03613	lb/cu inch
	8.3454	lb/gal (U.S.)
	0.35757	grains/cu ft
Grams/L	58.417	grains/gal (U.S.)
	1,000	parts per million
	0.062427	lb/cu ft
	8.345	lb/1000 gal (U.S.)
Grams/ml	0.999973	g/cu cm
Grams/sq cm	9.6784×10^{-4}	atmospheres
	980.665	dynes/sq cm
	10	kg/sq m
	2.04817	lb/sq ft
	0.0142234	lb/sq inch
	0.73556	mm Hg at 0°C
Gravity	980.665	cm/sec/sec
	32.174	ft/sec/sec
Hectares	2.471044	acres (U.S.)
	10,000	sq m
	11,959.85	sq yd (U.S.)
Horsepower	42.418	BTU (mean)/min
	10.688	kg calories (mean)/min
	33,000	ft-lb/min
	550	ft-lb/sec
	1.0139	horsepower (metric)
	0.74570	kilowatts
	745.70	watts
Horsepower (metric)	32,549	ft-lb/min
	0.98632	horsepower (U.S.)
	75	kg-m/sec
Horsepower-hour	641.304	kg calories (mean)
	1.9800×10^{6}	ft-lb
	2.6845×10^{6}	joules (abs.)
	2.7374×10^{5}	kg-m
	0.7457	kw-hr
Hours (mean solar)	0.041667	days (mean solar)
	0.0059524	weeks
Inches (U.S.)	2.5400×10^{8}	angstrom units
	2.540005	centimeters
	1.57828×10^{-5}	miles
	39,450.45	wavelengths of cadmium red line
Inches mercury at 32°F	0.033421	atmospheres
	3.38639×10^{4}	dynes/sq cm
	345.31	kg/sq m
	70.727	lb/sq ft
Inches water at 39.2°F (4°C)	0.0024583	atmospheres
	2,490.82	dynes/sq cm
	25.399	kg/sq m
	5.2022	lb/sq ft
Joule-seconds	1.5258×10^{33}	quanta
Joule-seconds/N_o[1]	2.5173×10^{9}	quanta
Joules (absolute)	9.480×10^{-4}	BTU (mean)
	0.23895	gram calories (mean)
	0.23918	gram calories (20°C)
	2.3889×10^{-4}	kg calories (mean)

/1/ Avogadro's number.

Column A	x Column B	= Column C
Joules (absolute)	3.485×10^{-4}	cu ft-atm
	1×10^{7}	ergs
	0.73756	ft-lb
	1.0197×10^{4}	g-cm
	3.72508×10^{-7}	horsepower-hr
	0.999680	joules (Int.)
	0.101972	kg-m
	2.77778×10^{-7}	kw-hr
	0.0098689	L-atm
Joules/°C	5.2679×10^{-4}	BTU (60°F)/°F
	0.23889	gram calories/°C
Joules/electron	6.2811×10^{19}	joules/abcoulomb
Joules/electron/°C	6.2811×10^{18}	joules/coulomb/°C
Joules/faraday	1.0363×10^{-4}	joules/abcoulomb
Joules/faraday/°C	1.0363×10^{-5}	joules/coulomb/°C
Joules/gram/°C	0.23889	gram calories (mean)/g/°C
Kilogram-meters	0.00929667	BTU (mean)
	2.3427	gram calories (mean)
	0.0034177	cu ft-atm
	9.80665×10^{7}	ergs
	232.71	ft-poundals
	7.2330	ft-lb
	3.6529×10^{-6}	horsepower-hr
	2.72407×10^{-6}	kw-hr
Kilograms	9.80665×10^{5}	dynes
	2.204622341	pounds (avoir.)
	2.6792285	pounds (troy)
Kilograms/m	0.67197	lb/ft
Kilograms/sq cm	14.223	lb/sq inch
	73.556	cm Hg at 0°C
Kilograms/sq m	9.6777×10^{-5}	atmospheres
	98.0665	dynes/sq cm
	0.1	g/sq cm
	0.204817	lb/sq ft
	0.00142234	lb/sq inch
	0.0032809	ft water
	0.0028959	inches Hg
	0.073556	mm Hg
Kilograms/sq mm	9.80665×10^{7}	dynes/sq cm
Kiloliters	35.317	cu ft
Kilometers	3,280.83	feet
	0.539593	miles (nautical)
	0.621369945	miles (U.S.)
	0.1	myriameters
	1,093.6	yards
Kilometers/hr	27.7778	cm/sec
	54.68	ft/min
	0.9113	ft/sec
	0.5396	knots/hr
	16.667	m/min
	0.27778	m/sec
Kilometers/hr/sec	27.778	cm/sec/sec
	0.9113	ft/sec/sec
	0.27778	m/sec/sec
Kilometers/min	1,666.7	cm/sec
	37.2822	mi/hr
Kilowatt-hours	3,413.0	BTU (mean)
	8.6001×10^{5}	gram calories (mean)
	2.6552×10^{6}	ft-lb
	1.3410	horsepower-hr
	3.6000×10^{6}	joules (abs.)
	3.6709×10^{5}	kg-m
Kilowatts	56.884	BTU (mean)/min
	14.3334	kg calories (mean)/min
	2.6552×10^{6}	ft-lb/hr
	1.3410	horsepower

continued

Appendix V. FORMULAS, FACTORS, AND CONSTANTS

Part II. CONVERSION FACTORS

Column A	x Column B	= Column C
Knots/hr	51.479	cm/sec
	1.15155	mi/hr
Lamberts	0.3183	candles/sq cm
	2.054	candles/sq inch
	1	lumens emitted/sq cm (perfectly diffusing surface)
Liter-atmospheres (normal)	24.206	gram calories (mean)
	0.035316	cu ft-atm
Liters	0.028378	bushels (U.S.)
	0.035316	cu ft
	61.025	cu inches
	0.001000027	cu m
	0.0013080	cu yd
	270.5179	drams (U.S., fluid)
	0.26417762	gallons (U.S.)
	33.8143	ounces (U.S., fluid)
	1.816192	pints (U.S., dry)
	2.11336	pints (U.S., liquid)
	0.908096	quarts (U.S., dry)
	1.056681869	quarts (U.S., liquid)
Liters/cm/da	0.011574	sq cm/sec
Liters/min	5.886×10^{-4}	cu ft/sec
	0.004403	gal/sec
Liters/sec	2.11896	cu ft/min
	15.8507	gallons (U.S.)/min
Lumens	0.001496	watts
Lumens/sq ft	1	footcandles
	10.764	lumens/sq m
Lumens/sq m	0.092902	footcandles/sq ft
	1×10^{-4}	phots
Megmhos	0.001	abmhos
	2.540	megmhos/cu inch
Megmhos/cu inch	0.39370	megmhos/cu cm
Mercury at $0^{\circ}C$	13.5951	g/cu cm
Meter-candles	1.000	lumens/sq m
Meters	1×10^{10}	angstrom units
	3.280833333	feet (U.S.)
	39.3700	inches (U.S.)
	5.39593×10^{-4}	miles (nautical)
	6.2137×10^{-4}	miles (statute)
	1×10^{9}	millimicrons
	1×10^{12}	millionth microns
	1.55316412×10^{6}	wavelengths of cadmium red line
	1.093611	yards (U.S.)
Meters/min	1.6667	cm/sec
	0.05468	ft/sec
	0.06	km/hr
	0.03728	mi/hr
Meters/sec	196.8	ft/min
	3.6000	km/hr
	0.060000	km/min
	2.2369	mi/hr
	0.03728	mi/min
Meters/sec/sec	3.6	km/hr/sec
	2.2369	mi/hr/sec
Mhos (International)/cu cm	0.99948	mhos (abs.)/cu cm
Microfarads	1×10^{-15}	abfarads
Microns	1×10^{4}	angstrom units
	1×10^{-4}	centimeters
	3.937×10^{-5}	inches
	0.001	millimeters
Microvolts/$^{\circ}F$	1.8000	microvolts/$^{\circ}C$

Column A	x Column B	= Column C
Miles (nautical)	6,080.20	feet
	1.85325	kilometers
Miles (U.S., statute)	63,360	inches
	5,280	feet
	1.609347219	kilometers
Miles/hr	44.7041	cm/sec
	88	ft/min
	1.4667	ft/sec
	0.8684	knots/hr
	26.82	m/min
Miles/hr/min	0.74507	cm/sec/sec
Miles/hr/sec	44.704	cm/sec/sec
	1.4667	ft/sec/sec
	0.44704	m/sec/sec
Miles/min	2,682.2	cm/sec
	88	ft/sec
Milligrams	0.01543236	grains
	5.64383×10^{-4}	drams (avoir.)
	2.57206×10^{-4}	drams (troy)
	3.52739×10^{-5}	ounces (avoir.)
	3.215074×10^{-5}	ounces (troy)
	2.2046×10^{-6}	pounds (avoir.)
	2.67923×10^{-6}	pounds (troy)
Milligrams/inch	0.38609	dynes/cm
Milligrams/L	1.0	parts per million
Milligrams/mm	9.80665	dynes/cm
Millilamberts	0.929	lumens/sq ft (with perfect diffusion)
Milliliters	1.000027	cu cm
	0.061025	cu inches
	0.2705179	drams (U.S., fluid)
	16.2311	minims (U.S.)
	0.0338147	ounces (U.S., fluid)
Millimeters	0.0393700	inches (U.S.)
Millimeters mercury at $0^{\circ}C$	0.00131579	atmospheres
	1,333.22	dynes/sq cm
	1.3595	g/sq cm
	13.595	kg/sq m
	2.7845	lb/sq ft
	0.019337	lb/sq inch
	1,000	microns Hg at $0^{\circ}C$
Millimicrons	10	angstrom units
	1×10^{-7}	centimeters
Minims (U.S.)	61.612	cu cm
	1/60	drams (U.S., fluid)
	0.0616102	milliliters
	1/480	ounces (U.S., fluid)
Minims (U.S., fluid)	0.061612	cu cm
Minutes (time)	6.94444×10^{-4}	days
	9.9206×10^{-5}	weeks
Months (mean calendar)	30.4202	days
	730.085	hours
	43,805.1	minutes
	2.6283×10^{6}	seconds
Oersteds (abs.)	1.00052	oersteds (Int.)
Ohm-mile-pounds	1.7513×10^{-4}	ohm-meter-grams
Ohms (absolute)	0.99948	ohms (Int.)
Ounces (avoirdupois)	16	drams (avoir.)
	7.29166	drams (troy or apoth.)
	437.5	grains
	28.349527	grams
	0.9114583	ounces (troy or apoth.)
	1/16	pounds (avoir.)
	0.075954861	pounds (troy)

continued

Appendix V. FORMULAS, FACTORS, AND CONSTANTS

Part II. CONVERSION FACTORS

Column A	x Column B	= Column C
Ounces (troy or apothecary)	17.55428	drams (avoir.)
	8	drams (troy or apoth.)
	480	grains
	31.103481	grams
	1.09714	ounces (avoir.)
	0.06857143	pounds (avoir.)
	1/12	pounds (troy)
Ounces (U.S., fluid)	29.5737	cu cm
	1.80469	cu inches
	8	drams (fluid)
	1/128	gallons (U.S.)
	0.0295729	liters
	480	minims (U.S.)
	1/16	pints (U.S., liquid)
Pints (U.S., dry)	0.015625	bushels (U.S.)
	550.61	cu cm
	33.6003	cu inches
	0.550599	liters
	0.5	quarts (U.S., dry)
Pints (U.S., liquid)	473.179	cu cm
	0.016711	cu ft
	28.875	cu inches
	6.1881×10^{-4}	cu yd
	128	drams (fluid)
	0.125	gallons (U.S.)
	0.473168	liters
	7,680	minims (U.S.)
	16	ounces (U.S., fluid)
	0.5	quarts (U.S., liquid)
Planck's quanta	6.554×10^{-27}	erg-seconds
Poises	1.000	g/cm/sec
Pound-feet (torque)	1.3558×10^{7}	dyne-cm
Pound-inches (torque)	1.1298×10^{6}	dyne-cm
Pounds	32.174	poundals
Pounds (avoirdupois)	256	drams (avoir.)
	116.6667	drams (troy)
	4.44852×10^{5}	dynes
	7,000	grains
	453.5924277	grams
	0.4535924277	kilograms
	16	ounces (avoir.)
	14.5833	ounces (troy)
	1.2152778	pounds (troy)
	4.464286×10^{-4}	tons (long)
	4.5359243×10^{-4}	tons (metric)
	5×10^{-4}	tons (short)
Pounds (troy)	210.6514	drams (avoir.)
	96	drams (troy)
	5,760	grains
	373.2418	grams
	13.165714	ounces (avoir.)
	12	ounces (troy)
	0.822857	pounds (avoir.)
	3.6735×10^{-4}	tons (long)
	3.7324×10^{-4}	tons (metric)
	4.1143×10^{-4}	tons (short)
Pounds/cu ft	0.016018	g/cu cm
	16.018	kg/cu m
	5.787×10^{-4}	lb/cu inch
Pounds/cu inch	27.68	g/cu cm
	2.768×10^{4}	kg/cu m
Pounds/ft	1.48816	kg/m
Pounds/gal (U.S.)	0.119826	g/cu cm
Pounds/gal (British)	0.099776	g/cu cm

Column A	x Column B	= Column C
Pounds/inch	178.6	g/cm
Pounds/sq ft	4.7252×10^{-4}	atmospheres
	478.78	dynes/sq cm
	0.48824	g/sq cm
	4.8824	kg/sq m
	0.0069445	lb/sq inch
	0.016018	ft water at 39.1°F
	0.35913	mm Hg at 0°C
Pounds/sq ft (moment of inertia)	4.2140×10^{5}	g/sq cm
	421.40	kg/sq cm
	144	lb/sq inch
Pounds/sq inch	0.068046	atmospheres
	68.946	dynes/sq cm
	70.307	g/sq cm
	0.070307	kg/sq cm
	703.07	kg/sq m
	144	lb/sq ft
	27.673	inches water at 39.2°F (4°C)
	51.715	mm Hg
Pounds/sq inch (moment of inertia)	2,926.4	g/sq cm
	2.9264	kg/sq cm
	0.00694444	lb/sq ft
Pounds water	27.68	cu inches
	0.1198	gallons (U.S.)
Pounds water (62°F)	0.016033	cu ft
Pounds water/min	0.016021	cu ft/min
	2.670×10^{-4}	cu ft/sec
Quarts (U.S., dry)	0.03125	bushels (U.S.)
	1,101.23	cu cm
	0.038889	cu ft
	67.2006	cu inches
	1.10120	liters
	0.125	pecks (U.S.)
	2	pints (dry)
Quarts (U.S., liquid)	946.358	cu cm
	57.749	cu inches
	0.033420	cu ft
	256.00	drams (fluid)
	0.25	gallons (U.S.)
	0.946333	liters
	32	ounces (fluid, U.S.)
	1.96841	quintals (metric)
Square centimeters	0.0010764	sq ft
	0.15500	sq inches
	0.00247107	sq links (Gunter's)
	1×10^{-4}	sq m
	100	sq mm
	1.1960×10^{-4}	sq yd
Square centimeters/day	1.1574×10^{-5}	sq cm/sec
Square feet	929.0341	sq cm
Square feet (U.S.)	2.29568×10^{-5}	acres
	144	sq inches
	0.09290341	sq m
	3.58701×10^{-8}	sq mi
	1/9	sq yd (U.S.)
Square inches (U.S.)	6.4516258	sq cm
	1/144	sq ft (U.S.)
	6.4516258×10^{-4}	sq m
	1/1296	sq yd (U.S.)
Square kilometers	247.1044	acres (U.S.)
	1.0764×10^{7}	sq ft
	1×10^{6}	sq m
	0.3861006	sq mi (U.S.)
	1.1960×10^{6}	sq yd

continued

Appendix V. FORMULAS, FACTORS, AND CONSTANTS

Part II. CONVERSION FACTORS

Column A	x Column B	= Column C
Square meters	2.471044×10^{-4}	acres (U.S.)
	1×10^{4}	sq cm
	10.76387	sq ft (U.S.)
	1,550.0	sq inches
	1×10^{-6}	sq km
	1×10^{6}	sq mm
	3.8610×10^{-7}	sq mi
	1.195985	sq yd (U.S.)
Square miles	640	acres
	2.78784×10^{7}	sq ft
	2.589998	sq km
	2,589,998	sq m
	3.0976×10^{6}	sq yd
Square millimeters	0.01	sq cm
	0.0015500	sq inches
	1×10^{-6}	sq m
Square mils	6.4516×10^{-6}	sq cm
	1×10^{-6}	sq inches
	6.4516×10^{-4}	sq mm
Square yards (U.S.)	2.06612×10^{-4}	acres (U.S.)
	8,361.31	sq cm
	9	sq ft
	1,296	sq inches
	0.83613	sq m
	3.22831×10^{-7}	sq mi
Statamperes	3.33560×10^{-10}	amperes (abs.)
Statcoulombs	3.33560×10^{-10}	coulombs (abs.)
	2.0947×10^{9}	electronic charges
Statcoulombs/kg	1.0197×10^{-6}	statcoulombs/dyne
Statcoulombs/lb	2.2481×10^{-6}	statcoulombs/dyne
Statfarads	1.11263×10^{-12}	farads (abs.)
Stathenries	8.98776×10^{11}	henries (abs.)
Statmhos	1.11263×10^{-12}	mhos (Int.)/cu cm
Statohms	8.98776×10^{11}	ohms (abs.)
Statvolts	299.796	volts (abs.)
Tons (long)	1,016.0470	kilograms
	2,240	pounds (avoir.)
	2,722.22	pounds (troy)

Column A	x Column B	= Column C
Tons (metric)	1,000	kilograms
	2,204.62	pounds (avoir.)
Tons (short)	8.8964×10^{8}	dynes
	907.1846	kilograms
	2,000	pounds (avoir.)
	2,430.56	pounds (troy)
	0.892857	tons (long)
	0.907185	tons (metric)
Tons (short)/sq ft	0.94509	atmospheres
Volts (absolute)	1×10^{8}	abvolts
	0.0033356	statvolts
	0.99955	volts (Int.)
Volts/°C	1.0000	joules/coulomb/°C
Watt-hours	3.4130	BTU (mean)
	2,655.3	ft-pounds
	860.01	gram calories (mean)
	0.0013410	horsepower-hr
	3,600	joules
	0.86001	kg calories (mean)
	367.09	kg-m
Watts (absolute)	1×10^{7}	ergs/sec
	44.254	ft-lb/min
	0.73756	ft-lb/sec
	0.0013410	horsepower
	0.0013596	horsepower (metric)
	1	joules/sec
	0.014333	kg calories (mean)/min
Watts (International)	1.00032	watts (abs.)
Watts/sq inches	8.1913	BTU/sq ft/min
	6,372.6	ft-lb/sq ft/min
	0.19310	horsepower
Weeks	168	hours
	10,080	minutes
	604,800	seconds
Yards (U.S.)	91.440183	centimeters
	5.68182×10^{-4}	miles
Years (sidereal)	365.256	days (mean solar)
	8,766.144	hours (mean solar)

Part III. NUMERICAL CONSTANTS AND BINOMIAL COEFFICIENTS

Constant	Value	Reciprocal	Logarithm
$1/4\ \pi$	0.7853981634	1.2732395447	$\bar{1}$.8950898814
$1/2\ \pi$	1.5707963268	0.6366197724	0.1961198770
π	3.1415926536	0.3183098862	0.4971498727
$2\ \pi$	6.2831853072	0.1591549431	0.7981798684
$\sqrt{\pi}$	1.7724538509	0.5641895835	0.2485749363
$\sqrt{2\ \pi}$	2.5066282746	0.3989422804	0.3990899342
$\sqrt{1/2\ \pi}$	1.2533141373	0.7978845608	0.0980599385
$1/2\sqrt{\pi}$	0.8862269255	1.1283791671	$\bar{1}$.9475449407
e	2.7182818285	0.3678794412	0.4342944819
e^2	7.3890560989	0.1353352832	0.8685889638
$\sqrt{2}$	1.4142135624	0.7071067812	0.1505149978
$\sqrt{3}$	1.7320508076	0.5773502692	0.2385606274
$\sqrt{10}$	3.1622776602	0.3162277660	0.5000000000
$\mathrm{Log}_{10}e$	0.4342944819	2.3025850930	$\bar{1}$.6377843113
Radian	57.2957795131°	0.0174532925	1.7581226324

n	Binomial Coefficients Value of n_x: 4	5	6	7	8	9	10	11	12
0	1	1	1	1	1	1	1	1	1
1	4	5	6	7	8	9	10	11	12
2	6	10	15	21	28	36	45	55	66
3	4	10	20	35	56	84	120	165	220
4	1	5	15	35	70	126	210	330	495
5		1	6	21	56	126	252	462	792
6			1	7	28	84	210	462	924
7				1	8	36	120	330	792
8					1	9	45	165	495
9						1	10	55	220
10							1	11	66
11								1	12
12									1

continued

Appendix V. FORMULAS, FACTORS, AND CONSTANTS

Part IV. PHYSICAL CONSTANTS

Speed of light in a vacuum; also, ratio of emu to esu of electric charge (c)	$(2.99776 \pm 0.00004) \times 10^{8}$ m/sec
Charge of an electron (e)	$(1.6020 \pm 0.0002) \times 10^{-19}$ coulomb
Faraday's constant (F)[1]	$(96{,}522 \pm 7)$ coulombs/mole
Avogadro's number (N_o)[2]	$(6.0251 \pm 0.0004) \times 10^{23}$
Standard atmospheric pressure (P_o)	$(101{,}324.6 \pm 0.4)$ nt/sq m
Freezing point of water on the absolute (Kelvin) scale (T_o)	(273.16 ± 0.02) °K
Density of mercury at STP	$(13{,}595.04 \pm 0.06)$ kg/cu m
Atomic weight of oxygen, physical scale[3]	(16.00436 ± 0.00009)
Volume of a mole of perfect gas at STP (V_o)	$(22{,}420.7 \pm 0.6)$ cu cm
Universal gas constant (R_o)	$(8{,}316.6 \pm 0.4)$ joules/kg·°K
Boltzmann's constant (k), the gas constant per molecule	$(1.3803 \pm 0.0001) \times 10^{-23}$ joule/°K
Mass of atom of unit atomic weight (m_1), physical scale[3]	$(1.6589 \pm 0.0014) \times 10^{-24}$ g
Mass of electron (m_e)	$(9.103 \pm 0.008) \times 10^{-28}$ g
Mechanical equivalent of heat	$(4{,}185.5 \pm 0.4)$ joules/kcal
Gravitation constant (G)	$(6.670 \pm 0.005) \times 10^{-11}$ nt·sq m/sq kg
Planck's (quantum) constant (h)	$(6.623 \pm 0.001) \times 10^{-34}$ joule·sec

/1/ The charge transported by a gram atom of a univalent element. /2/ The number of molecules in a gram molecule, or of atoms in a gram atom. /3/ An atomic weight of 16 for oxygen (as determined by chemical analysis) is the basis for the chemical scale of atomic weights. In the physical scale the value of 16 is assigned to the most abund[illegible] isotope of oxygen. Physical scale atomic weights are larger than those in the chemical scale, by a ratio of 1.0002 [illegible] 1.

Appendix VI. ATOMIC WEIGHTS

Values in parentheses are mass numbers of the most stable known isotopes.

	Element	Symbol	Atomic No.	Atomic Wt.		Element	Symbol	Atomic No.	Atomic Wt.		Element	Symbol	Atomic No.	Atomic Wt.
	(A)	(B)	(C)	(D)		(A)	(B)	(C)	(D)		(A)	(B)	(C)	(D)
1	Actinium	Ac	89	(227)	35	Gold	Au	79	197.0	69	Praseodymium	Pr	59	140.92
2	Aluminum	Al	13	26.98	36	Hafnium	Hf	72	178.50	70	Promethium	Pm	61	(147)
3	Americium	Am	95	(243)	37	Helium	He	2	4.003	71	Protactinium	Pa	91	(231)
4	Antimony	Sb	51	121.76	38	Holmium	Ho	67	164.94	72	Radium	Ra	88	(226)
5	Argon	Ar	18	39.944	39	Hydrogen	H	1	1.0080	73	Radon	Rn	86	(222)
6	Arsenic	As	33	74.91	40	Indium	In	49	114.82	74	Rhenium	Re	75	186.22
7	Astatine	At	85	(210)	41	Iodine	I	53	126.91	75	Rhodium	Rh	45	102.91
8	Barium	Ba	56	137.36	42	Iridium	Ir	77	192.2	76	Rubidium	Rb	37	85.48
9	Berkelium	Bk	97	(249)	43	Iron	Fe	26	55.85	77	Ruthenium	Ru	44	101.1
10	Beryllium	Be	4	9.013	44	Krypton	Kr	36	83.80	78	Samarium	Sm	62	150.35
11	Bismuth	Bi	83	209.00	45	Lanthanum	La	57	138.92	79	Scandium	Sc	21	44.96
12	Boron	B	5	10.82	46	Lead	Pb	82	207.21	80	Selenium	Se	34	78.96
13	Bromine	Br	35	79.916	47	Lithium	Li	3	6.940	81	Silicon	Si	14	28.09
14	Cadmium	Cd	48	112.41	48	Lutetium	Lu	71	174.99	82	Silver	Ag	47	107.880
15	Calcium	Ca	20	40.08	49	Magnesium	Mg	12	24.32	83	Sodium	Na	11	22.991
16	Californium	Cf	98	(251)	50	Manganese	Mn	25	54.94	84	Strontium	Sr	38	87.63
17	Carbon	C	6	12.011	51	Mendelevium	Md	101	(256)	85	Sulfur	S	16	32.066[1]
18	Cerium	Ce	58	140.13	52	Mercury	Hg	80	200.61	86	Tantalum	Ta	73	180.95
19	Cesium	Cs	55	132.91	53	Molybdenum	Mo	42	95.95	87	Technetium	Tc	43	(99)
20	Chlorine	Cl	17	35.457	54	Neodymium	Nd	60	144.27	88	Tellurium	Te	52	127.61
21	Chromium	Cr	24	52.01	55	Neon	Ne	10	20.183	89	Terbium	Tb	65	158.93
22	Cobalt	Co	27	58.94	56	Neptunium	Np	93	(237)	90	Thallium	Tl	81	204.39
23	Copper	Cu	29	63.54	57	Nickel	Ni	28	58.71	91	Thorium	Th	90	232.05
24	Curium	Cm	96	(247)	58	Niobium	Nb	41	92.91	92	Thulium	Tm	69	168.94
25	Dysprosium	Dy	66	162.51	59	Nitrogen	N	7	14.008	93	Tin	Sn	50	118.70
26	Einsteinium	Es	99	(254)	60	Nobelium	No	102	(254)	94	Titanium	Ti	22	47.90
27	Erbium	Er	68	167.27	61	Osmium	Os	76	190.2	95	Tungsten	W	74	183.86
28	Europium	Eu	63	152.0	62	Oxygen	O	8	16	96	Uranium	U	92	238.07
29	Fermium	Fm	100	(255)	63	Palladium	Pd	46	106.4	97	Vanadium	V	23	50.95
30	Fluorine	F	9	19.00	64	Phospborus	P	15	30.975	98	Xenon	Xe	54	131.30
31	Francium	Fr	87	(223)	65	Platinum	Pt	78	195.09	99	Ytterbium	Yb	70	173.04
32	Gadolinium	Gd	64	157.26	66	Plutonium	Pu	94	(242)	100	Yttrium	Y	39	88.92
33	Gallium	Ga	31	69.72	67	Polonium	Po	84	(210)	101	Zinc	Zn	30	65.38
34	Germanium	Ge	32	72.60	68	Potassium	K	19	39.100	102	Zirconium	Zr	40	91.22

/1/ The Atomic Weights Commission recommends a range of ±0.003.

Appendix VII. LOGARITHMS AND ANTILOGARITHMS

Part I. FOUR-PLACE LOGARITHMS

No.	0	1	2	3	4	5	6	7	8	9	PP 1	PP 2	PP 3	PP 4	PP 5	PP 6	PP 7	PP 8	PP 9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
No.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

continued

Appendix VII. LOGARITHMS AND ANTILOGARITHMS

Part I. FOUR-PLACE LOGARITHMS

No.	0	1	2	3	4	5	6	7	8	9	Proportional Parts 1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4
No.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

continued

Appendix VII. LOGARITHMS AND ANTILOGARITHMS

Part II. FOUR-PLACE ANTILOGARITHMS

Log 10	0	1	2	3	4	5	6	7	8	9	Proportional Parts 1	2	3	4	5	6	7	8	9
.00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
.09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
.17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
.20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
.22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
.23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
.27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
.30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
.31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
.37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
.38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
.42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
.45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
.47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
.49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6
Log 10	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

continued

Appendix VII. LOGARITHMS AND ANTILOGARITHMS

Part II. FOUR-PLACE ANTILOGARITHMS

Log 10	0	1	2	3	4	5	6	7	8	9	Proportional Parts 1	2	3	4	5	6	7	8	9
.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
.52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
.58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
.59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
.64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
.72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
.75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
.82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
.84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
.87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	6	7	9	11	13	14	16
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20
Log 10	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9

INDEX

It is suggested that the index be used in conjunction with the table of contents: the index to locate data for a specific organism, and the table of contents to determine the scope of the data for a particular topic. To facilitate identification, the index includes the taxonomic order for animals, and the family for plants, unless otherwise specified. Aa a further aid, the index lists the animals and plants as they are presented in the tables. Entries for a particular organism may therefore be found under the common name, under the scientific name, or under both. Where information is available under both, cross-references make the data easily accessible.

* indicates diagram, drawing, or graph
Fn. indicates footnote material

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3 REPORT TITLE

4 DESCRIPTIVE

Supersedes

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NIH GM 0653

b PROJECT NO

7164

c Task No.

716406

d

10 AVAILABILIT

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Available,

Experiment

11 SUPPLEMENT

Joint sponso

* National

** National

13 ABSTRACT

The Biolog
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